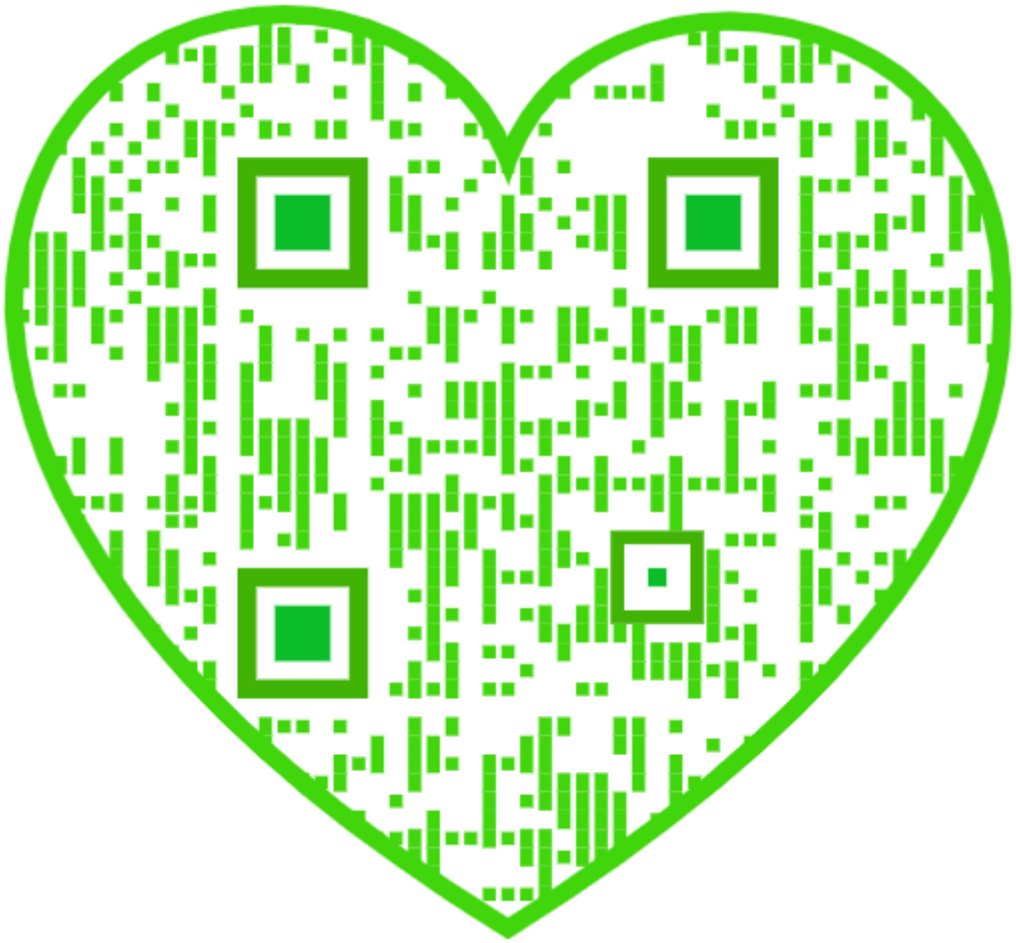
# OXY-ACETYLENE WELDING



# OXY-ACETYLENE WELDING

# OXY-ACETYLENE WELDING

A COMPREHENSIVE TREATISE ON THE PRACTICE OF WELDING CAST IRON, MALLEABLE IRON, STEEL, COPPER, BRASS, BRONZE, AND ALUMINUM BY THE OXY-ACETYLENE METHOD, TOGETHER WITH CONCISE INFORMATION ON THE EQUIPMENT REQUIRED FOR BOTH WELDING AND CUTTING BY THIS PROCESS

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# PREFACE

TEN years ago the oxy-acetylene method of welding and cutting metals was hardly more than a laboratory process, but in the course of these few years it has become one of the most important of the methods in the metal-working industries. It has made possible the making of repairs of broken machine parts that previously had to be replaced by entirely new castings or forgings. Not only has the process proved of the utmost importance in repair work, but its application has also been found to be of the greatest value in the manufacture of many articles. Much has been published relating to this process, but a great deal of that which has been placed on record in the past has been descriptive of odd jobs. It is, therefore, believed that the present volume, dealing in a more systematic manner with the principles and practice of the art of oxy-acetylene welding, will be of considerable value to those engaged in the metal trades.

The information here presented on the subjects of oxy-acetylene welding and cutting has been mainly furnished by S. W. Miller, proprietor of the Rochester Welding Works, whose wide experience in the practical application of the process and whose success in the work vouch for the reliability of the information here placed on record. The experience of the author in the oxy-acetylene welding field has been unusually extensive, but having been mostly on repair work, he has written especially for those engaged in a similar line. A great deal of the work done with the oxy-acetylene welding torch is on repairs, and while there are also a great many applications of it in manufacturing work, such applications are more or less special in each case, and sometimes require a great deal of experimenting before success is attained. The general principles here presented, however, apply equally to repair and manufacturing work.



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In the publication of this volume the Publishers have also made use of several articles by other authors, especially articles by Julius Springer, which from time to time have been published in MACHINERY. A chapter on "Lead Burning," by James F. Hobart, has also been included. This material has been added in order to give as complete and comprehensive information as possible. In general, time and cost data have purposely been omitted in the chapters on oxy-acetylene welding, because, in the present state of the art, it is difficult, if not impossible, to give accurate cost data on repair work. Two welders, working on repairs of a similar character, will often vary as much as fifty per cent in the time consumed, and, as shop conditions also vary to a great extent, it is almost impossible to give accurate figures regarding cost.

This volume describes the equipment required for oxy-acetylene welding and cutting, deals in detail with the methods used for welding cast iron, malleable iron, steel, copper, brass, bronze, and aluminum, and gives, in addition, special attention to the welding of sheet metal, tank welding, boiler repairs, etc., as well as to the subject of lead burning, which is really a kind of autogenous welding. All of the information given has been obtained from the most authoritative sources, the descriptions of the welding apparatus and gas generators having been furnished by the manufacturers in each case, and has been subjected to careful and painstaking editorial work by the staff of MACHINERY'S Book Department, by whom all the volumes in MACHINERY'S Mechanical Library have been prepared. Hence, the Publishers believe that the present volume on oxy-acetylene welding and cutting equipment and practice will be found to be of very great value in the metal-working field.

THE PUBLISHERS.

NEW YORK, *July*, 1916.

## AUTHOR'S NOTE

In preparing these chapters, the author has had in mind his own early experience in oxy-acetylene welding, and recognizes that, at best, much experimenting must be done, because no descriptions, however complete, can fully cover all the small details of successful welding work; but the author has endeavored to cover the principles that are of general value and application. He believes that photographs are, in most cases, superior to long descriptions, and has, to a large extent, acted upon this belief. All of the photographs shown are of successful work done in his own shops, with the exception of less than half a dozen, which were added by the publishers.

The author knows of no book devoted to repair work, and although descriptions of work done have appeared from time to time, in the mechanical papers, they do not appear to be as complete as desirable, and, for this reason, the writing of this book was undertaken. The author believes that equally good results may be obtained in other ways than those which he describes; but all methods described have produced thoroughly reliable and successful results, and he knows that what he has done others can do by following the same procedure. Beginners, especially, are advised to avoid apparent short cuts, which are liable to prove costly when not used by a welder of judgment and experience.

The metallurgical side of oxy-acetylene welding is of great interest and importance, but it has not as yet been studied as thoroughly as will be required for the highest development of the art. In the chapters that follow, however, the requirements of the practical man have been kept in view, and the

theory has been avoided as much as possible. The author hopes that the information imparted will prove of service to those engaged in the art of oxy-acetylene welding, the possibilities of which have only begun to be developed.

S. W. MILLER.

ROCHESTER, *July*, 1916.

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# OXY-ACETYLENE WELDING

## INTRODUCTION

### AUTOGENOUS AND FUSION WELDING

DURING the past fifteen years several valuable processes for joining metal parts have been developed, which, to a considerable extent, have taken the place of ordinary forge welding, soldering, and brazing, which latter methods are very old and which have been used from time immemorial. Not only have the new processes that have been developed taken the place of the older processes, in many instances, but entirely new fields have been opened up for the application of welding, and to-day various methods of welding — autogenous, electric, and thermit — are applied to metals under conditions where the ordinary forge welding process would be wholly inadequate.

Forge welding is applicable only to the joining of parts of wrought iron and low-carbon steel. It is true that high-carbon steel, and some of the other metals, may also be welded by this method, but these welds are not always satisfactory and are never as strong as the metal itself. Soldering can be used only on small light work for joints which are exposed to ordinary temperatures, or temperatures only slightly above the boiling point of water, the reason for this being that the melting point of most soldering alloys is about 400 degrees F. Brazing, that is, the joining of metal parts by the fusion of a so-called "spelter solder," is applicable to iron, steel, copper, brass, and several other metals, but, on many kinds of work, the process is rather uncertain in its results, even when in the hands of experts, unless a good equipment is provided for controlling the heat and manipulating the work. Because of these limitations of the older

processes, the newer processes have had a very rapid development, and have within comparatively few years become recognized as among the most important of the methods used in the metal-working field. The three most important of these new welding methods are the electric welding process, the thermit welding process, and the autogenous welding process, the latter of which is dealt with in the following chapters.

**Fusion Welding.** — Welding is understood generally to mean the uniting of two pieces of iron or steel by heating them to the temperature at which they become softened or pasty, without melting them, placing them together, and by hammering, or in some other way, bringing them into intimate contact. As is well known, this cannot be done with any of the common metals except wrought iron or steel. The process of fusing and uniting metals by the application of intense heat from a gas flame without compression or hammering is generally known as "autogenous welding." The temperature required is obtained by the combustion of a gas containing carbon or hydrogen, or both, by the aid of pure oxygen. Acetylene is the gas generally used, although hydrogen is also employed. The gases are thoroughly mixed in a torch or blowpipe to insure perfect combustion, which takes place at the nozzle or tip. A modification of the welding torch is also utilized for the cutting of iron and steel by heating and burning away the metal by oxidizing it.

The word "autogenous," used in connection with the name of this process of welding, is not, however, strictly accurate. Autogenous means "self-produced," and this application of the word is not descriptive of a weld made by the oxy-acetylene process. One idea that should be conveyed by any word describing a weld of this kind is that it is made with the same kind of metal as that of which the piece is composed. That is, it is not a joining or soldering process, but, strictly speaking, a welding process. The word "autogenous," however, does not convey this meaning. Another idea that should be conveyed by the name of the process is that it involves the melting of the metal during the making of the weld. Probably there is no word which conveys all of the ideas involved, but "homogeneous"

would better explain the uniformity of the character of the weld than "autogenous." This, however, is a long word and is not especially descriptive of the process, as one of the essential features of the process is the melting of the metal, and hence it would seem that the term "fusion welding," which is short, descriptive, and distinctive, should be entirely satisfactory. However, the expression "autogenous welding" has become a term so generally used that it seems doubtful if any other expression, even though more expressive and definite, will ever replace it.

In oxy-acetylene welding the weld may be formed directly between the two adjoining surfaces, but, more commonly, it is formed by fusing in additional material between the surfaces of the joint. This material is in the form of a rod or wire, and may or may not be of the same composition as the material being welded.

**Development of Oxy-acetylene Welding Process.** — Autogenous welding is generally spoken of as a modern development, and this, of course, is true as regards its present commercial application. As a matter of fact, however, it is known that the Romans used a fusion welding method for the joining of lead pipes a century or two before Christ. As they had no knowledge, however, of producing the high temperatures required for the autogenous welding of metals having a high melting temperature, the early application of the fusion welding process was limited to lead, the melting point of which is about 620 degrees F. The process of autogenous welding by means of the oxy-acetylene torch or blowpipe dates back only to the year 1900. About that time the process had its inception in France, the first experimenter being Edmund Fouché, of Paris, who, in conjunction with Picard, devised the first practical oxy-acetylene welding torch in 1901, and who, after a couple of years of experimenting, succeeded in producing a commercially successful apparatus.

For some time, however, the process remained more or less of a laboratory method, and the commercial development of oxy-acetylene welding and cutting may be said to have taken place

during a brief period beginning about 1905. Considering the short time during which this development has taken place, the process has reached remarkably high perfection and efficiency. Apparatus and equipment for gas welding are now made by a number of manufacturers in the United States and Europe. The principles involved in the use of the apparatus of different makes are practically the same, the differences being mainly in the construction of the torches and the manner in which the gases are generated. Oxygen and acetylene are most generally used, although oxygen and hydrogen are also employed, especially in metal cutting. Great difficulties were at first met with in cheaply producing pure oxygen. The cheap production of acetylene had been generally solved through the extensive development of acetylene lighting; but the means for generating and storing this gas have also been further developed so as to meet all the requirements of metal welding and cutting work. Nevertheless, while these advances have been made, the cost of the gases is still at such a point that there is a vast amount of work that cannot be done by the oxy-acetylene process, which will in future be so done, when the cost of gases is still further reduced.

**Application of the Process.** — The oxy-acetylene welding process is used both in the manufacture of articles, the parts of which would otherwise be riveted or joined by other means, and in repair work. In both fields it has proved to be of exceptional value. In the manufacture of many articles the rapidity with which the joints can be made and the comparatively high efficiency of the welds make it of great importance; in repair work it has made possible the saving of many parts which otherwise would have to be thrown away, such as broken automobile cylinder castings, crankcases, and parts of all kinds of machinery. Some special applications are found in the reclaiming of cracked castings in foundries, the filling of blow-holes in castings, the adding of metal to worn surfaces to secure the original thickness, the welding of piping without removal, the filling of drilled holes that have been incorrectly located, and the sealing of riveted seams to secure absolutely tight joints, which cannot

be done effectively by calking. In cutting, the blowpipe is used for cutting out steel-plate shapes, cutting holes in steel plates, cutting off piping, cutting off risers from steel castings, cutting structural beams, and for cutting up steel wreckage, etc.

The importance of the autogenous welding process for producing reliable joints in thousands of manufactured articles which are now brazed, riveted, or bolted together is obvious. In many fields the process has revolutionized past manufacturing methods, decreased cost of production, and made possible the placing on the market of articles that are not only cheaper, but better, more reliable, or more convenient, than those previously made by other methods. The process, of course, has its limitations, as will be pointed out in the subsequent chapters of this treatise on oxy-acetylene welding and cutting, which will deal in detail with the equipment used for producing the required gases and for perform ing the welding operation, the preparation of the stock for welding, the materials used for filling in at the joints, the fluxes required when welding, and the practice followed in making oxy-acetylene welds in all the common metals to which the process is applicable.

# CHAPTER I

## EQUIPMENT FOR OXY-ACETYLENE WELDING

THE equipment required for oxy-acetylene welding includes torches, hose, oxygen and acetylene generators and containers, reducing valves, and pressure gages. In addition, the welding shop must be provided with a number of simple machine tools, special tables or benches, and a few simple appliances or jigs that can be used for various classes of work. In the manufacturing plant where oxy-acetylene welding is used extensively for a few operations continuously repeated, highly developed special tools and fixtures are employed. Only the best apparatus should be purchased, and, as in many other cases, it is advisable to know that the manufacturer is sound financially and is going to continue in the business. The patent situation with regard to welding equipment, and even in regard to certain processes, is somewhat confused at the present time, and it is well to be sure that, after it is cleared up, repair parts can be obtained. The manufacturers of the best apparatus have more experience and are able to give assistance and information to the beginner which is not obtainable elsewhere. Poor apparatus is expensive to operate and, therefore, costly, even when the purchase price may appear low.

**The Welding Torch.** — The first practical welding torch was devised by Fouché and Picard in France in 1901, and the first industrial application was made by them in 1903, after many experiments to avoid the danger from explosion. It was also found necessary to take care of "back-firing." If a tube of comparatively large diameter is filled with a mixture of gas and air, and ignited at one end, the flame will travel to the other end at a certain speed, depending chiefly upon the nature of the gas, but also on some other considerations, such as the size of the

pipe. It has been found that it is necessary to have a very small pipe to prevent this action in the case of a mixture of acetylene and oxygen, and also that the speed of travel of the flame is very high in the case of this mixture. The dangers resulting from not taking proper precautions to prevent such flame-travel are well illustrated in the terrific mine explosions which have occurred and which have been duplicated in experiments on full-sized tunnels in which the speed of travel of the flame of burning mine gases has been accurately measured. It is evident, however, that if the mixture of gases issues from the end of the pipe with a velocity greater than that with which the flame travels backward in the pipe, it will burn without any danger. In the early torches with comparatively large acetylene openings, it was necessary to provide a chamber in the torch filled with asbestos and provided with wire gauze partitions to prevent this back-firing; but it was later found possible to do away with this precaution, if the acetylene holes in the head of the torch were made sufficiently small.

**Requirements of a Good Welding Torch.** — There are a large number of torches on the market, some of which are good and some of which are bad. One of the most essential features of a torch is the use of as little oxygen as possible in proportion to the acetylene used; early torches were very defective in this respect. The result of this was unsatisfactory welds, particularly in steel or any metal which is easily oxidized, such as aluminum. Modern torches give much better results, and it is believed that still further progress will be made in the future. The actual amount of oxygen used should be the same as that of acetylene, and this is quite closely approached at the present time in some torches.

Good welding can be done with any good torch; as stated, the best is the one which uses the least oxygen in proportion to acetylene, because it is less expensive in operation and tends to give a more neutral flame. The number and sizes of the torches depend upon the character of work to be done, but there should always be a full set of tips provided. If this is not done, experience proves that a time will come unexpectedly when a tip not on hand will be needed. Hose should be of the best quality.

It is subject to quite heavy strains, and, as the lighter the torch is, the easier it is to handle, the best quality is necessary to avoid excessive wear.

The intensity of the flame from an oxy-acetylene torch is the highest that can be produced by the burning of gases. It is impossible to measure the temperature directly, but from theoretical considerations it has been determined that it is about 6300 degrees F. When it is considered that the melting point of cast iron is about 2100 degrees F., that of soft steel about 2600 degrees F., and of wrought iron about 2700 degrees F., it will be seen that there is no difficulty whatever in melting any of the metals.

**Types of Oxy-acetylene Welding Torches.** — Leaving aside those torches which use acetylene under very high pressures, and which are not in use in the United States, all torches may be divided into two classes: those of the so-called "injector" type, in which the acetylene is under a very low pressure, say, about six ounces, and those in which the acetylene pressure is considerably higher, varying from one to six pounds, depending upon the size of the tip. These latter torches are generally called "medium-pressure" torches. The pressures referred to are those given on the gages of the regulating valves, and while these pressures have to be used by the welder, to regulate the flame of the torch, they are not the pressures that really produce the gas mixture. These latter pressures depend entirely upon the dimensions and locations of the orifices through which the gases pass. It is stated at times that a certain torch of a certain design is an "equal-pressure" torch, meaning thereby that the gage pressures are equal. This, however, is no criterion of the actual pressures of the gases at the work, and it is very easy, by changing the dimensions of the passages, to change any torch from one that uses twice as much oxygen pressure as acetylene pressure, to one using equal oxygen and acetylene pressures, or even less oxygen pressure than acetylene pressure, all of the pressures referred to being those shown by the gages. The essential difference, therefore, is the acetylene pressure, and this is what should be used as a classification basis.

With regard to the pressures as shown by the gages, it should be mentioned that a poor gage is liable to produce bad results, and it is a fact that many gages do not register correctly, particularly at the low pressures at which the acetylene is used; so that, if the gage registers incorrectly, it is possible to obtain too small or too large a flame, either of which is liable to give bad results. Pressure gages should, therefore, be tested at intervals

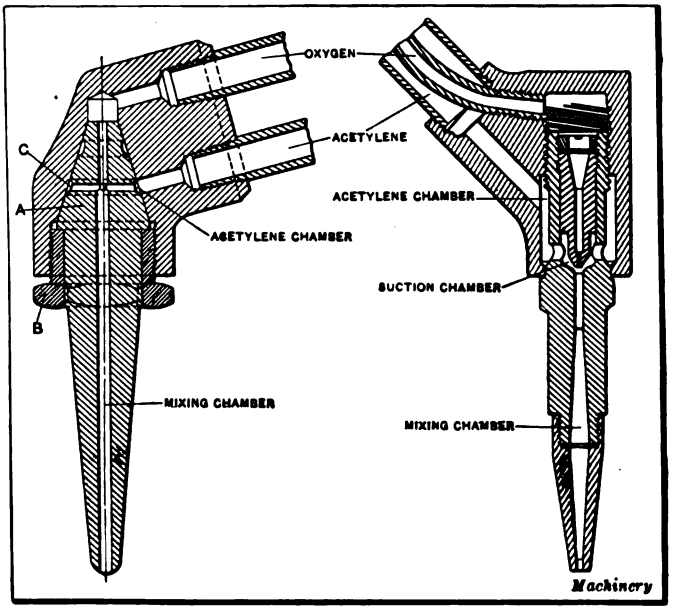


Fig. 1. Tip of So-called "Positive-pressure" Torch

Fig. 2. Tip of Low-pressure Torch

and adjusted, so that they will give as close results as possible over the range in which they are used.

**Low-pressure Torches.** — The low-pressure torch works on the injector principle, the oxygen being under high pressure, so that it flows rapidly through the duct in the head of the torch and draws in the acetylene. As the two gases flow through the duct or mixing chamber in the head or burner tip, they are mixed together ready for combustion to take place as they emerge from the orifice at the end of the tip.

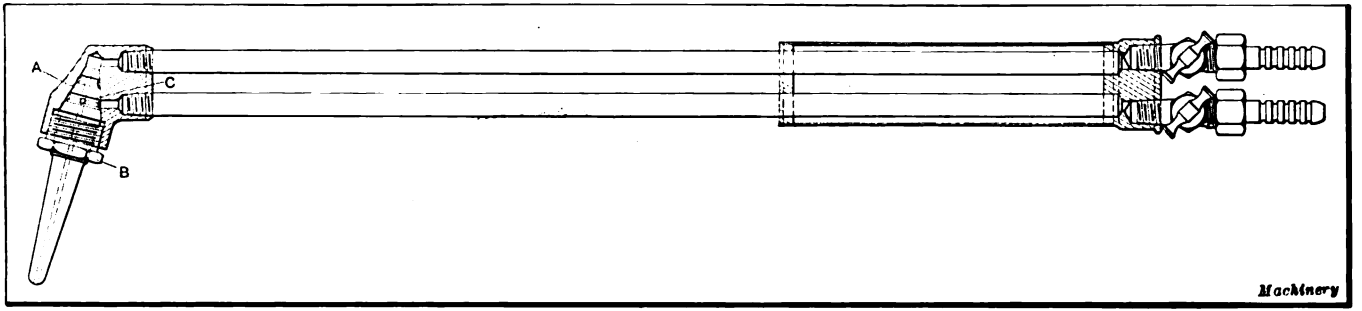


Fig. 3. Standard Type Positive-pressure Welding Torch as made by the Davis-Bournonville Co.

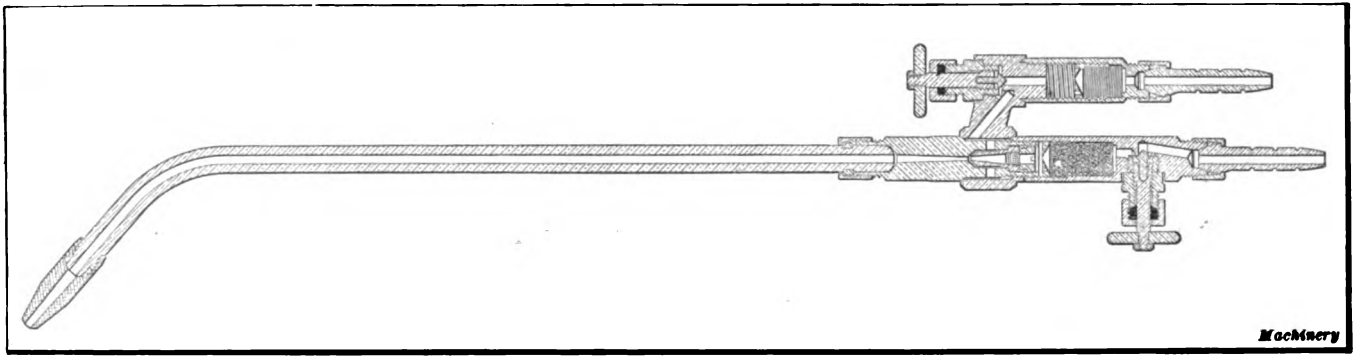


Fig. 4. Type of Welding Torch made by the Prest-O-Lite Co.

**Medium-pressure Torches.** — The term "medium-pressure" is employed to distinguish torches of this type from the high-pressure torches which were used in France at the time that the oxy-acetylene welding and cutting industry was in the early stages of its development. This name also distinguishes the medium-pressure torch from the low-pressure torch in which the acetylene is delivered at slightly above atmospheric pressure.

In the medium-pressure torch, both gases are under considerable pressure, so that the flow of acetylene does not depend upon the injector principle. It will be noted that, in both types of torches, the oxygen and acetylene travel through a duct of considerable length, so that a complete mixture is obtained by the time the orifice at the tip is reached. Figs. 1 and 2 illustrate medium- and low-pressure torches.

**Commercial Designs of Torches.** — Figs. 1 and 3 show the design of welding torch which has been adopted as a standard construction by the Davis-Bournonville Co. This torch is made in different sizes to meet the requirements of various classes of work. One of the basic principles of this type of torch — which was covered in the original French patent and also by patents in the United States — provides for using different sizes of interchangeable burner tips in a given size of torch, in order to adapt it for handling various kinds of work. The gases enter the tip at separate points, and the pressure of each gas is regulated to obtain exactly the required mixture. Each tip provides a size of flame suitable for various classes of work. In this connection, it is interesting to note that a patented construction has been employed for fitting the burner tip into the head of the torch. Instead of using a threaded joint, it will be noted that the tip is tapered at *A* to fit a tapered socket in the head of the torch. This does away with trouble from damaged threads which resulted from the earlier construction in which the tip was screwed into the head; and leakage caused by expansion or contraction of the different parts of the torch due to variations in the temperature has been done away with. It will, of course, be evident that the tip is held in place in the head of the torch by the nut *B*, and that the oxygen enters the tip through the axial duct,

while the acetylene enters the groove *C* which leads the gas to the four ports or transverse ducts in the tip.

Each of the two sizes in which this torch is made is provided with five different sizes of tips. The five smaller sizes provide for welding metal from $\frac{1}{32}$ up to $\frac{1}{4}$ inch in thickness, while the five larger sizes are employed for heavy welding operations on metal from $\frac{1}{4}$ inch in thickness and up. When using each size of tip, a definite specified pressure of the oxygen and acetylene is secured through the use of pressure regulators. The pressure of the oxygen and the size of the axial duct in the tip bear such a relation to the pressure of the acetylene and the size of the ports or transverse ducts that the ratio between the consumption of oxygen and acetylene is 1.14 to 1, which gives a neutral flame.

Fig. 2 shows a cross-section of the welding head of the Oxweld low-pressure or injector type of torch, as made by the Oxweld Acetylene Co. The notation in the illustration shows the construction clearly. Fig. 4 shows a type of torch which differs in its arrangement to a considerable extent from the other two types shown. This is made by the Prest-O-Lite Co. This torch is used for compressed or medium-pressure acetylene only, and, therefore, no injector device is necessary. The gases mix near the handle, and flow together along the full length of the stem. The handle of the torch is fitted with "anti-back-fire" chambers for both gases, filled with material through which it is impossible for the flame to pass.

**Cutting Torches.** — In cutting iron and steel with the oxy-acetylene torch, the cut is made by the burning away of the metal along the line on which the cut is to be made. In order to understand the operation of the cutting torch, the reader must first grasp the idea that the burning of any matter — regardless of whether it is coal, oil, wood, or metal — is due to the chemical combination of the oxygen with the material which is being burned. In the case of iron and steel this burning action can only take place at very high temperatures, and for this reason the metal is heated by means of the oxy-acetylene flame, which raises its temperature to a point where the metal will combine

with the oxygen; but ordinary air consists of one part of oxygen to four parts of nitrogen, and as a result the cutting action would be quite slow if additional oxygen were not supplied. In the early forms of cutting torches this was done by attaching a separate tip at the side of the welding torch, which was connected to a third tube that carried an auxiliary supply of oxygen and discharged it against the heated metal. The flow of oxygen through this auxiliary tip was controlled by means of a valve which was held open by depressing a thumb-lever.

To avoid the use of this construction, and to provide a cutting torch on which only two hose connections are required, the Davis-Bournonville Co. is now manufacturing a torch of the form shown in Fig. 5. In this torch there are two rubber tubes which connect the torch with the supply of oxygen and acetylene. The torch itself is provided with three metal tubes, *A*, *B*, and *C*, and the tip is drilled with three longitudinal ducts, *D*, *E*, and *F*. Each of the ducts *D* and *E* delivers a mixed supply of oxygen and acetylene which burns at the tip of the burner, serving to heat the metal to the oxidizing temperature. So far as the method of effecting the mixture of the oxygen and acetylene is concerned, each of the ducts *D* and *E* is analogous to the ducts of the welding tip which has already been described. The central duct *F* delivers a supply of pure oxygen to the metal when the thumb-lever *G* is thrown over to open the valve in tube *A* to the oxygen supply. This pure oxygen strikes the metal which has been heated to a high temperature by the oxy-acetylene flame and causes a rapid oxidation or burning of the metal to take place. In this way the metal is burned away along the line of the cut, but with a narrow saw-like kerf which, when the cutting is skillfully done, does not give the metal the appearance of having been burned or melted. The torch is made with three sizes of interchangeable tips for cutting different thicknesses of metal. The smallest tip cuts metal from $\frac{1}{4}$ to $\frac{3}{4}$ inch in thickness, the medium tip from 1 to 3 inches in thickness, and the largest size from 3 inches in thickness up. As in the case of the welding tips, each size of cutting tip uses the oxygen and acetylene under specified pressures.

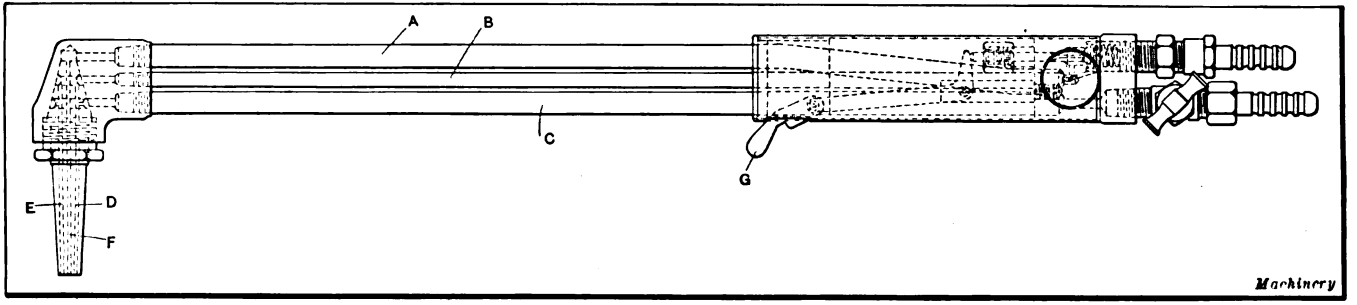


Fig. 5. Davis-Bournonville Cutting Torch

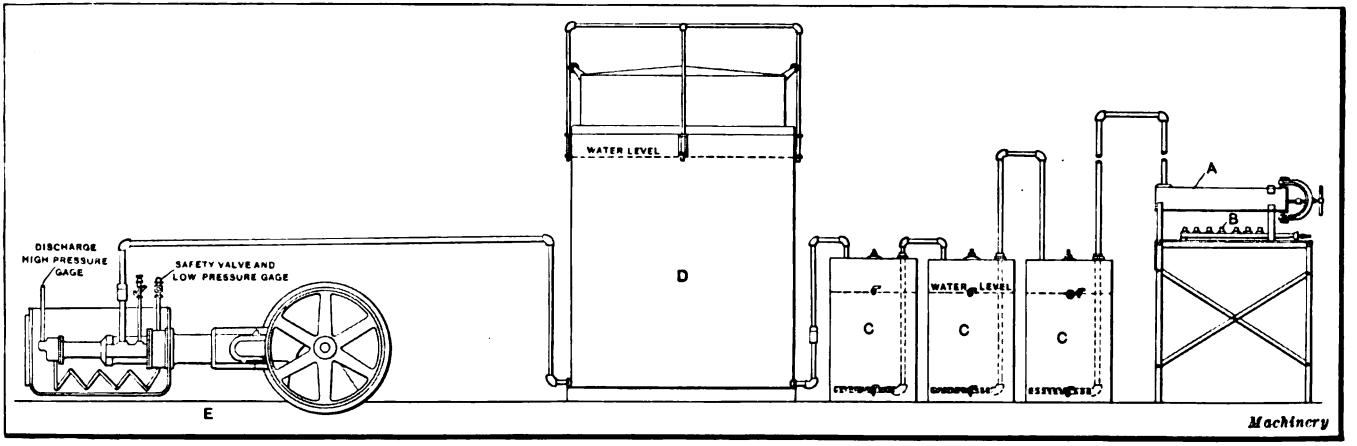


Fig. 6. Diagrammatic View of Potassium-chlorate Oxygen Plant

**Examples of Torches for Different Purposes.** — Fig. 7 shows a group of the different styles of welding and cutting torches manufactured by the Davis-Bournonville Co. A large size of

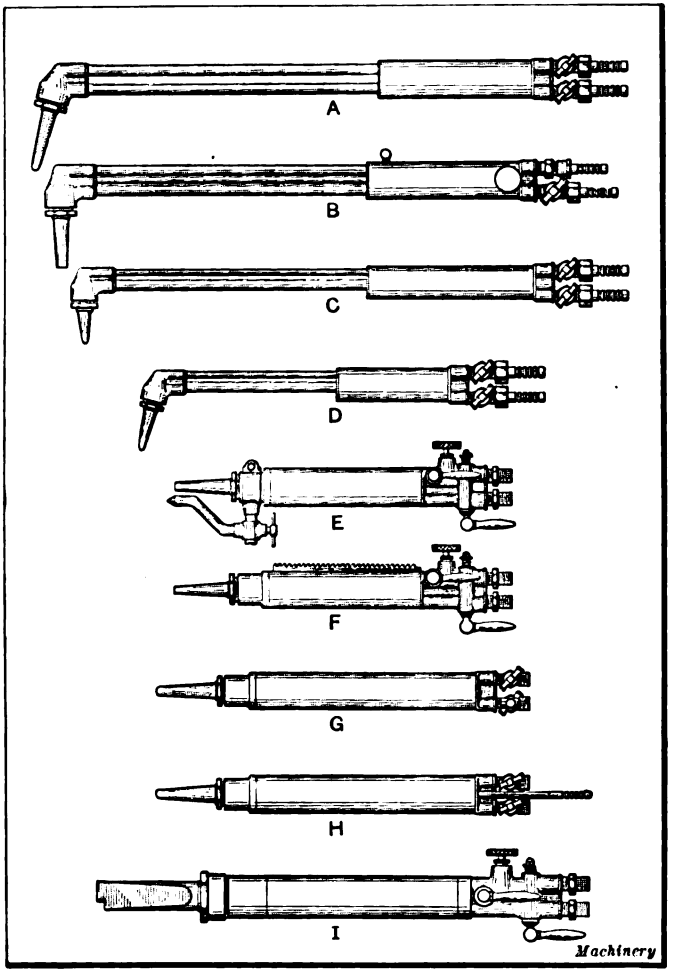


**Fig. 7. Different Types of Cutting and Welding Torches**

welding torch is shown at *A*, this being a standard torch for performing medium and heavy welding operations in making boiler repairs, and for general shop work. The torch is fitted with a set of the five large-sized welding tips, and is adapted for

welding metal from $\frac{5}{16}$ inch in thickness up. It is 20 inches long and weighs 2 pounds. A special torch of this size is made in a 3-foot length for very heavy work where it is desirable to enable the operator to get as far away from the work as possible, owing to discomfort experienced from the intense temperature of the metal. The standard two-hose cutting torch is shown at *B*. This torch is 20 inches long and weighs 40 ounces. What is known as a "manufacturers" torch is shown at *C*. This torch meets the requirements for light and medium sheet-metal welding; it is especially adapted for manufacturing operations on boilers, steel barrels, iron and steel tanks, cylinders, etc. A small size of the standard welding torch is shown at *D*, this torch being convenient for use on light and medium sheet-metal welding and on light repair work. It is 14 inches in length and weighs

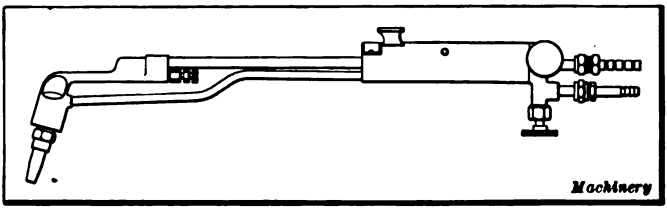


**Fig. 8. Oxweld Cutting Torch**

18 ounces. This torch is provided with a set of the five small-sized tips and is adapted for welding metal from $\frac{1}{32}$ to $\frac{5}{16}$ inch in thickness. A torch for circular hand cutting is shown at *E*. This torch is of the same general type as the standard cutting torch, but is fitted with a compass attachment to adapt it for cutting circular holes. Torches for use on cutting and welding machines are shown at *F* and *G*, and a torch with water-cooled head and tips at *H*. This type is for use on heavy welding where there is a tendency for the head and tip of the torch to become overheated from the intense heat radiated by the metal that is being operated upon. This is especially true in cases where the head of the torch is surrounded by the heated metal, and, to overcome this difficulty, a supply of cooling water is circulated through the head and tip by means of two extra hose connections provided for the purpose. At *I* is shown an oxy-

hydrogen cutting torch in which hydrogen gas is burned in place of acetylene.

In Fig. 8 is shown the Oxweld cutting torch, which differs from the welding torch made by the same concern mainly in that an additional oxygen duct is provided.

**British Cutting Torch.** — The cutting torch most generally used in Great Britain is that known as the "Universal," and is made by the British Oxygen Co. This company has acquired from L'Oxhydrique Internationale a patent which gives it exclusive rights for any form of torch which employs a separate jet of oxygen for cutting purposes.

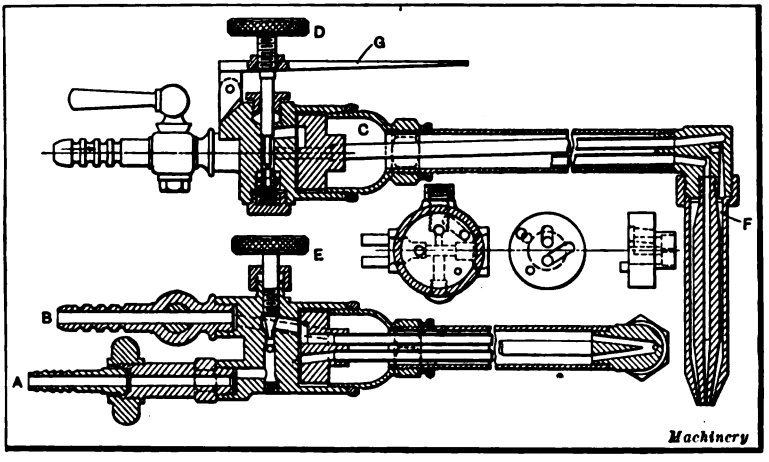


**Fig. 9. British Type of Cutting Blowpipe**

The torch, on which only two flexible tubes are required, is shown in Fig. 9. The oxygen for heating and cutting enters at *A*. Acetylene gas from a generator or an acetylene cylinder enters at *B*. The oxygen is distributed at *C*, the cutting oxygen being controlled by a valve at *D*, and the heating oxygen by a valve at *E*. The gases for heating are mixed in the annular passage *F*, and, burning at the nozzle, serve to heat the metal to the cutting temperature. So far as the method of effecting the mixture of the oxygen and acetylene is concerned, it is analogous to that of the welding torch. The central passage delivers a supply

of pure oxygen to the metal when the thumb-valve *D* is opened. This valve is capable of double control, as it can be operated by the hand lever *G*. The pure oxygen strikes the metal, which has been heated to a high temperature by the oxy-acetylene flame, and causes rapid oxidation to take place. In this way the metal is removed from along the line of the cut, leaving a narrow saw-like cut which, if the cutting has been skillfully done, does not give the metal the appearance of having been burned or melted. The torches are made with five different sizes of cut-

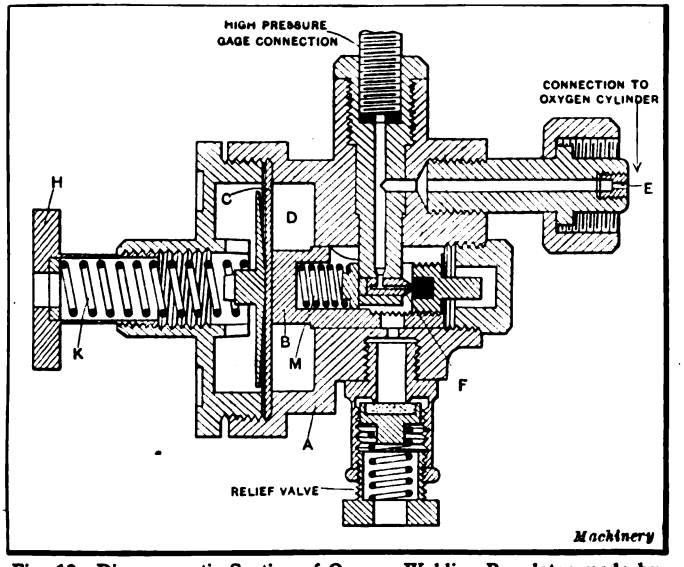


**Fig. 10. Diagrammatic Section of Oxygen Welding Regulator made by the Oxweld Acetylene Co.**

ting nozzles for cutting different thicknesses of metal. The smallest tip cuts metal from $\frac{1}{4}$ to $\frac{3}{4}$ inch in thickness, the next size cuts metal from 1 to 6 inches in thickness, the next from $6\frac{3}{4}$ to 9 inches, the next from $9\frac{3}{4}$ to 14, and the last, 17 inches in thickness. As in the case of welding torches, each thickness to be cut uses the oxygen under specified pressure.

**Regulating Valves.** — Regulating valves should be kept in good condition. Unless this is done, so that the reduced pressure remains constant under all conditions, the action of the

torch will be irregular and unsatisfactory. In the course of time the diaphragms become buckled and have to be renewed. This and dirt in the small passages are the only difficulties in a well-designed valve. Gages and regulating valves should be suitable for the work and of substantial design. The gage capacity should be about one and one-half times the maximum pressure used. The gages for welding-torch pressures should be graduated in single pounds, and need not have over 50 pounds capacity. For cutting torches, the gages should be graduated to about 250 pounds. Good gages give practically no trouble.

Fig. 10 shows a section of the Oxweld Acetylene Co.'s oxygen welding regulator which reduces the oxygen tank pressure, about 1800 pounds, to that necessary for welding, as the latter pressure does not exceed from 10 to 30 pounds. Its action is as follows: the oxygen enters from the tank through passage *E* to valve *F*, the seat for which is held away from the valve by the spring *K* acting through the diaphragm *C*, which can be adjusted by turning handle *H*, to obtain any desired pressure. The oxygen then passes into chamber *D*, and when there is sufficient pressure, the diaphragm is forced to the left, allowing the small spring *M* to pull the valve seat against the valve and shut off the supply of oxygen. As soon as the pressure falls, the action is reversed, and the supply of oxygen is renewed. The oxygen passes from the chamber *D*, through a connection not shown, to the hose. The regulator for cutting is similar in design to that for welding, but as the cutting pressure may run up to 100 pounds, it is made heavier, and provides for a larger flow of gas. The differences in conditions make it necessary to use different regulators for welding and cutting, and good results will not be obtained unless the proper regulator is used.

**Hydraulic Safety Valves.** — An essential detail for low-pressure welding and cutting installations is some form of safety valve. The personal safety of the operator and the protection of the piping and generating plant make it indispensable. Its function is to divert any oxygen traveling along the acetylene tube, due to disturbance in the torch or any other cause, and to extinguish any explosion wave reaching the valve. Many

devices have been tried, and experience shows that the only reliable device is some form of water valve. A common form is shown in Fig. 11. The acetylene gas enters at *A* and bubbles through the small holes at the lower end of the inlet tube. The gas leaves the body of the valve *B* by the valve *H*, the flexible tube connecting the valve and the torch being attached at *C*. The water level is fixed by the cock *F*. A branch tube *D* with a funnel *E* open to the atmosphere, or closed with a loose cover, is attached practically midway between the level of the water given by *F* and the level of the upper exit holes in the inlet tube. The figure shows the valve in the working position, the cocks *G* and *H* being open and the cock *F* closed. In the event of the oxygen traveling along the acetylene tube, or the return of an explosion wave, the sudden increase of pressure in the valve destroys the seal in the tube *D*, by forcing the water into the atmosphere and by the sealing of the acetylene inlet tube, thus allowing the explosive mixture to escape into the atmosphere.

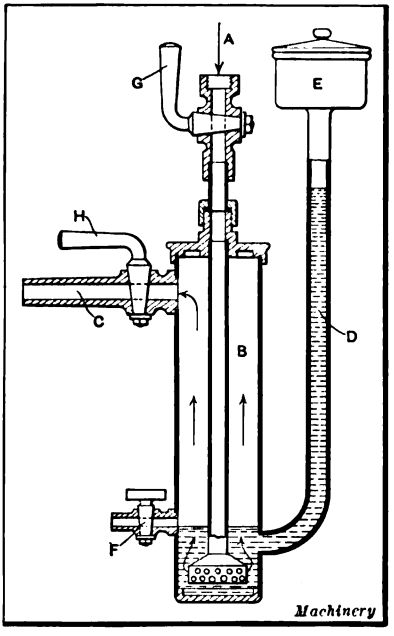


**Fig. 11. Hydraulic Safety Valve**

The simple type of valve just described has been modified with a view to restoring the water level after the return of oxygen; dealing with explosions in the valve; sounding an alarm in case of insufficient water; sealing the acetylene inlet tube in case of insufficient water. Such modifications are valuable where important equipment and numerous welders are engaged. The charging of the valve and its supervision should be the most important duty of the welder. Its position should be such that

all valves are within easy reach, and it should be possible to examine the interior periodically and to change the water regularly.

An ordinary water bottle, such as is sometimes used, is quite unsatisfactory, and, in fact, dangerous. The reason for using a back-pressure valve is one of such importance that only one correctly proportioned should be employed.

**Adjusting the Welding Torch.** — Before lighting the torch, the regulator on the acetylene line should be set to give the required pressure. The acetylene is then lighted and turned on full. The oxygen is then turned on, and the pressure varied by means of the regulator, until the two cones which appear in the flame at first are merged into one smaller cone. After this cone is formed, no more oxygen should be added. It is also well to occasionally test the cone by decreasing the oxygen pressure slightly, which will immediately cause an extension at the point of the cone. When the cone is properly formed, it will be neutral, so that it will neither oxidize (burn) nor carburize the metal. An excess of oxygen will cause burning and oxidation, whereas an excess of acetylene will carburize the metal. The tip of the cone should just touch the metal being welded, but not the point of the torch, as this might cause a "flash back." An excessive discharge of sparks indicates that too much oxygen is being used and that the metal is being burned or oxidized, although, when welding thick metals, there will be a considerable volume of sparks, even though the flame is neutral.

**Size of Torch Tip.** — The proper size of tip to use for welding depends upon the thickness of the work and the rate at which the heat is dissipated. Sometimes the rate of conduction and radiation is affected by the location of the parts to be welded. In general, heavy parts will conduct the heat more rapidly from the working point, and to offset this loss of heat a larger tip is used. In any case, the tip should be as small as is compatible with good work, to economize in the use of gases. If the flame is too small for the thickness of metal being welded, the heat will be radiated almost as fast as produced; hence, the flame will have to be held so long at one point to affect a weld that the metal may be burned. On the other hand, if the flame is too large

the radiation may be insufficient to prevent burning the molten metal. The tip should give a flame that will reduce the metal to a plastic, molten condition (not too fluid), covering a width approximately equal to the thickness of the metal being welded.

**Temperatures.** — The temperature of the oxy-hydrogen flame is approximately 4000 degrees F., and the temperature of the oxy-acetylene flame is about 6300 degrees F. With the oxy-acetylene flame, the number of British thermal units per cubic foot of gas is about five times as great as that obtained with the oxy-hydrogen flame.

**Care of Apparatus.** — Torches and other apparatus must be given proper care. If anything is found wrong, such as leaks in connections, these should be repaired at once, and, if the tips are defective and cannot be repaired, new tips should be provided. In heavy welding, the torch tips, if made of brass, are liable to be overheated unless means are provided for cooling the tip. This is done by keeping a pail of water near by, in which the end of the tip is dipped when necessary. The whole head of the torch should not be dipped, as this is liable to distort the end of the tip at the seat and cause a leak. The best method is to gradually dip the end of the tip into the water, thus cooling it slowly. After the entire tip is cooled, the head may also be cooled off, but not rapidly.

**Oxy-acetylene Apparatus.** — There are three general types of oxy-acetylene apparatus in use at the present time, namely:

1. Portable apparatus.

2. Apparatus consisting of an acetylene generator, a manifold for attaching oxygen tanks, or a storage tank for oxygen, and a system of piping extended throughout the shop.

3. Apparatus using both oxygen and acetylene generators, with a system of piping.

The field of the portable outfit is for all sorts of outside work. It may also be used in shop work, but is rather clumsy, due to the weight of the tanks used to contain acetylene; although in small shops, on account of its low cost, and sometimes because of its infrequent use, it is the proper type to use. For all-around effectiveness, the second type of apparatus is superior for gen-

eral shop practice. Practically its only drawback is the first cost of the generator, plant, and piping system. Once installed, it is extremely flexible in operation. No help is required to move tanks around, and the cost of the gas is very much less, being only about one-third that of compressed acetylene. The third type of apparatus is practically the same as the second except that the oxygen as well as the acetylene is generated on the ground. The principal disadvantage of the system is its very high cost, no matter what process is used. Also, in some cases, the residue from the generator is very disagreeable to handle.

**Methods for Producing Oxygen.** — Oxygen is a gas which constitutes about 20 per cent of the air in the atmosphere, the other 80 per cent being nitrogen, a gas which does not support combustion. Oxygen, however, is the active agent in maintaining life and combustion; its properties have been known since the end of the eighteenth century. Oxygen can be produced in several ways at such a price as to make it commercially useful.

**Liquid-air Process.** — At the present time the largest proportion of oxygen is made by the liquid-air process invented by Dr. Linde in 1897. Almost every one remembers the demonstrations a few years ago of liquid air, and of the many curious and interesting things that were done by its use. Most of these things, however, were mere laboratory experiments, and its most important application, that of producing oxygen for commercial use, was not thought of at that time. The possibility of producing oxygen in this way has been one of the chief factors in promoting the use of oxy-acetylene welding, as it has reduced the cost of the oxygen. The process simply consists in liquefying air and allowing it to again vaporize. The boiling points of oxygen and nitrogen are considerably different; hence, the gas desired may be collected and the other allowed to evaporate. The oxygen, after purification, is compressed into cylinders or tanks, and can then be shipped wherever it is desired for use. The principal impurity in oxygen thus made is nitrogen, a percentage of which is likely to be present, and which, even when small, has an adverse effect on a weld, and is particularly objectionable when using a cutting torch.

**Electrolytic Process.** — The next most important process for producing oxygen is the electrolytic. The decomposition of water by electric current into its two elements oxygen and hydrogen, has been practiced for many years; but it was not until the cost of electric current was reduced to a low point that it was possible to use this process commercially. It was also found by experiment and test that the production of an efficient and safe electrolytic cell was not an easy matter. It is, however, at the present time, a thoroughly practical process, and one which is gaining ground daily. It is exceedingly flexible, and while the cost of cells is prohibitive for a small plant, yet, where considerable oxygen is used with regularity and the expense can be afforded, it is much used, as it produces the purest commercial oxygen. The only impurity in it of any importance is a small percentage of hydrogen, which does not injure the weld, nor is it of disadvantage in cutting, as it burns, producing heat.

**Chlorate-of-potash Process.** — There are a number of other processes for producing oxygen, the only important one being by heating chlorate of potash in a retort, passing the gas through a washing apparatus, and collecting it in a gasometer. It can then be compressed to the required pressure and used as needed. Oxygen should never be generated from chlorate of potash under a pressure of more than a few ounces, on account of the danger of explosion. Oxygen, particularly when moist, as after passing through a washer, attacks the piping, etc., resulting in a weakening of the pipes, which cannot be generally detected in time to prevent serious results. Oxygen is also liable to cause an explosion when it is heated and comes into contact with any carbonaceous material, such as splinters of wood, in the retort. Serious accidents have occurred from this cause. The method, however, is perfectly safe if care is taken and the apparatus is procured from reliable manufacturers. The generation of oxygen from chlorate of potash under pressure is considered much more hazardous.

The gas produced by the chlorate-of-potash process is quite expensive, and contains a certain amount of chlorine which is detrimental to the strength of the welds and, therefore, unsat-

isfactory. This chlorine, however, can be removed entirely if proper apparatus is used, and, under certain circumstances, as where the cost of shipping tanks back and forth is very high, the use of chlorate of potash for generating oxygen may be advisable. At the present time the European war has greatly increased the cost of chlorate of potash, and this should be considered in making estimates.

**Commercial Oxygen.** — As commercially used in the oxy-acetylene welding industry, oxygen may be made or bought. The latter is the cheaper method, if the location is near a large plant making oxygen as a commercial product, as it saves the installing of a somewhat expensive apparatus. If it is necessary to make oxygen, either on account of cost or irregularity in delivery, the best process on a small scale is the heating of chlorate of potash in closed retorts, the resulting gas being passed through washers and collected in a gasometer, as described, from which it is pumped into tanks by a small compressor, generally belt-driven. The usual maximum pressure in the tanks is about 300 pounds, and they generally have a capacity of 100 cubic feet of oxygen measured at atmospheric pressure. These tanks are convenient for shop use, but for outside work they are somewhat heavy and bulky, and can be replaced with advantage by smaller tanks of the same capacity, but having a pressure of about 1800 pounds per square inch. These tanks are not sold, but are furnished, filled with oxygen, by the oxygen companies on reasonable terms, and, when empty, may be returned for refilling. Oxygen can be obtained in this way much more cheaply and conveniently under ordinary conditions than by making it. It should be noted that all tanks shipped must comply in all respects with the requirements of the Federal Bureau of Explosives.

**Potassium-chlorate Method of Oxygen Generation.** — A diagrammatic view of the apparatus used for making oxygen by the potassium-chlorate method is shown in Fig. 6. The potassium chlorate is sealed in a retort *A* and heated by gas burners *B*. The heating causes the potassium chlorate to give off oxygen, but this reaction would proceed too rapidly if the charge placed in the retort consisted of pure potassium chlorate. It

has been found, however, that, by mixing 13 pounds of manganese dioxide with 100 pounds of potassium chlorate, the chemical reaction will proceed more slowly. The manganese dioxide plays no part in the chemical reaction, but is merely used as a retarding agent. Ten pounds of the mixture is put in the retort at a time. The gas from the retort is delivered through a series of three washers *C*, which serve to remove impurities, after which it passes on and is collected in the gasometer *D*. From the gasometer, the oxygen is piped to the compressor *E*, which compresses it into cylinders at the required pressure ready for use. The purity of the oxygen obtained by this method is slightly over 97 per cent.

**Manufacture of Oxygen by the Liquid-air Process.** — In the manufacture of oxygen by the liquid-air process, the oxygen is obtained by making a separation of the oxygen and nitrogen, which are the chief constituents of air. This is done by first bringing the air to the liquid condition by the combined action of high pressure and low temperature, and then separating the oxygen from the nitrogen by taking advantage of the difference in the boiling points of these two constituents of the air when in the liquid condition. This method allows oxygen to be obtained at a relatively low cost, but the plant required is only suitable for working on a large scale. Consequently, the method is suitable for the use of manufacturers of oxygen rather than for the users of welding and cutting torches who desire to make only enough oxygen for their own use. It is for this reason that many users of welding and cutting torches have found it more advantageous to buy their oxygen in cylinders ready for use than to make their own supply in a potassium chlorate or an electrolytic plant.

To meet the demand from this class of consumers, generating plants have been established in the most important industrial centers throughout the United States. These plants supply oxygen to the consumer, which is contained in pressure cylinders ready for use; and, as a result of these numerous plants, many consumers get the advantage of buying their oxygen without having to pay freight on the filled cylinders or on the empty ones

which must be returned to the generating plants. In many cities where there is not enough manufacturing to warrant the maintenance of generating plants, warehouses have been established in which a supply of filled oxygen cylinders is carried so that orders can be promptly filled; but in these cases the price is necessarily higher, as freight charges must be included.

It has already been stated that the method by which oxygen is obtained from the mixture of nitrogen and oxygen in the air consists of first bringing the air to the liquid condition by the combined application of high pressure and low temperature, and then separating the oxygen and nitrogen by allowing the nitrogen to boil off from the mixed liquid. Fig. 12 shows a diagrammatic view of the plant employed for this purpose. This diagram gives a comprehensive idea of the principle involved and the general character of the equipment which is used. The diagram is presented simply as an adjunct to the following description, and many details have been omitted. It is well known that atmospheric air contains appreciable quantities of carbon dioxide, and the first step in the manufacture of oxygen by the liquid-air method is to remove the carbon dioxide. This is done by drawing the air through a pit containing lime, which absorbs the carbon dioxide by a chemical reaction resulting in the formation of a compound known as calcium carbide. After leaving the lime pit, the air goes to a five-stage compressor, in which the pressure is raised to 3000 pounds per square inch, and means are provided for cooling the air between each stage of compression, so that it leaves the compressor at about room temperature. After leaving the compressor, the air is delivered through pipe *A* to the "fore-cooler," in which the first reduction of temperature is effected. This fore-cooler is equipped with three sets of coils. The first coil contains carbon dioxide supplied from an external refrigerating system, and the other two coils contain the oxygen and nitrogen gases which have already been separated from the liquid air and are at very low temperatures.

As a result of its passage through the fore-cooler, the temperature of the air has been reduced to about 0 degrees C. After passing through the fore-cooler, the air enters pipe *B*, which

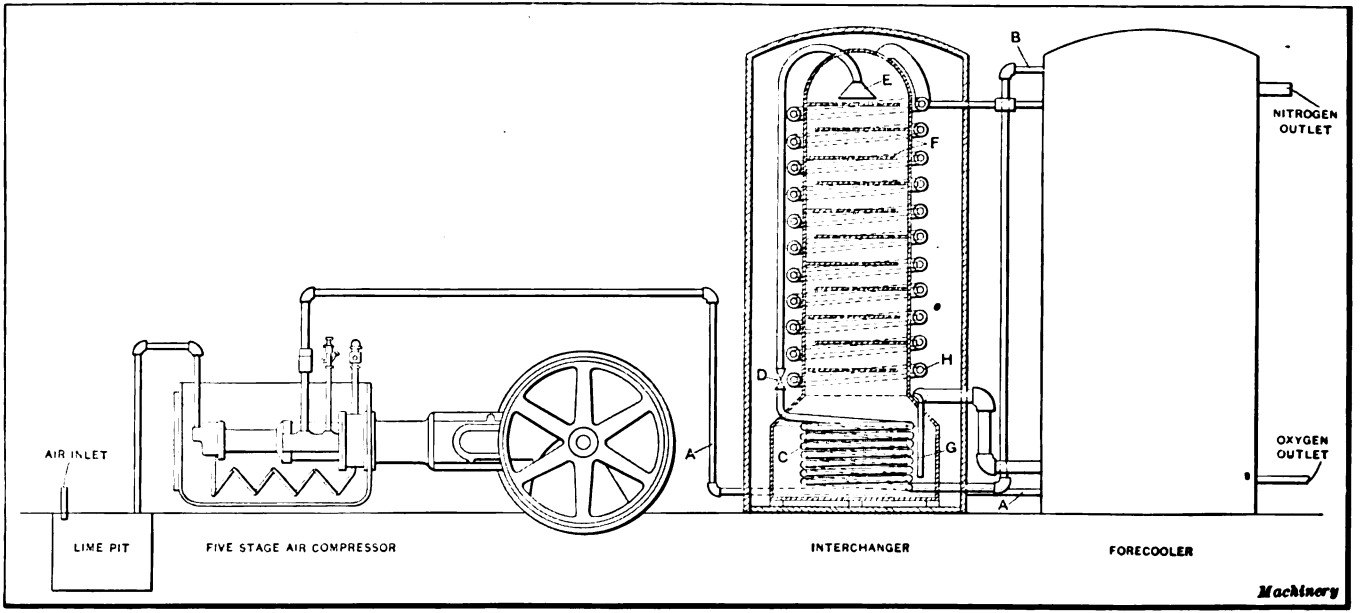


**Fig. 12. Diagrammatic View of a Liquid-air Oxygen Plant**

carries it to a third unit of the plant, known as an "interchanger." This pipe *B* leads to a coil *C*, which is submerged in the liquid air in the interchanger, and the purpose of passing the air through this coil will be subsequently explained. After leaving the coil *C*, the air, which it will be remembered is at a pressure of 3000 pounds per square inch, is allowed to pass through an expansion valve *D*, where the pressure is suddenly released. This results in a rapid expansion of the air, that, in turn, causes a further reduction of temperature, with the result that the air is brought to the liquid condition by this application of the Thomson-Joule principle. The liquid air passes through the vertical pipe to the top of the interchanger, where it is discharged through the atomizer *E*, which is located at the top of a tower filled with perforated baffle plates *F*. The liquid air passes down over these baffle plates and finally reaches the container in which the coil *C* is submerged.

We are now in a position to go back to the reference which was made to the purpose of the coil *C*. It will be recalled that the air left the fore-cooler at a temperature of approximately 0 degrees, and although this is a relatively low temperature, it is quite high when compared with the boiling points of liquid nitrogen and oxygen, which are 194 and 184 degrees C. below zero, respectively. The result is that the passage of the air through coil *C* causes the liquid in the container to boil in the same way that a coil containing high-pressure steam would cause water to boil. But as the boiling point of nitrogen is 10 degrees higher than that of oxygen, the nitrogen must be removed from the liquid before the oxygen will start to boil. The result is that the nitrogen passes up through the baffle plates *F* in the tower, and in so doing heats the liquid air sufficiently to remove a large part of the nitrogen before the liquid actually reaches the container. The boiling of the nitrogen sets up a pressure in the interchanger which is sufficient to force the liquid oxygen up through the pipe *G* into the inner tube of the double coil *H* which surrounds the tower in which the baffle plates *F* are located; and the nitrogen which has been removed from the mixture passes down through the outer tube of the coil *H* which

surrounds the tube carrying the oxygen. The result is that the oxygen gradually rises through the inner tube of the coil, and while doing so changes from the liquid to the gaseous condition. In order to keep the temperature of the interchanger down, the coils and other portions of the apparatus are carefully insulated by packing the space in the outer case with lamb's wool which effectually prevents the absorption of heat from the outside.

After passing through the coil *H* in the interchanger, the pipes containing the oxygen and nitrogen — which are still at a very low temperature — are carried over to the fore-cooler, where they enter two coils. It will be recalled that, in the preceding description of the fore-cooler, mention was made of these coils through which the low-temperature oxygen and nitrogen were passed. The purpose is to utilize the low temperature of these gases to assist the carbon-dioxide coil in reducing the temperature of the air as it passes through the fore-cooler on its way to the interchanger. After passing through the coil in the fore-cooler, the oxygen and nitrogen pass out through pipes, and the oxygen is ready to be collected in compression cylinders. At the present time the only use for the pure nitrogen which is made by this method is in incandescent electric light bulbs. Nitrogen is very suitable for this purpose, because it is chemically inert, and so does not have any effect upon the incandescent filament. Research work is also done with the view of developing a method of "fixing" the nitrogen; i.e. of developing a method of chemically combining the nitrogen with some other element or elements so that it may be used as a fertilizer, and in various chemical industries. The Linde Air Products Co. is prepared to guarantee a purity of 98.5 per cent for its oxygen, and, as a matter of fact, the purity is in the neighborhood of 99 per cent. The 1 per cent of impurity is nitrogen, which is chemically inert, so that it has little detrimental effect upon the steel or other metal which is being welded.

**The Electrolytic Method of Generating Oxygen.** — For those shops which use oxygen in sufficient quantities to warrant the installation of a plant for generating the gas by the electrolysis

of water, there is probably no more satisfactory method. It is well known that water is composed of two parts of hydrogen chemically united to one part of oxygen, and that when an electric current is passed through water — with the necessary amount of sodium hydroxide, potassium hydroxide, or some other chemical dissolved in it to make the solution a conductor of electricity — the chemical bond between the hydrogen and oxygen will be broken down. The result is that hydrogen gas is given off at the cathode or negative pole, and that oxygen is liberated at the anode or positive pole of the electrolytic cell.

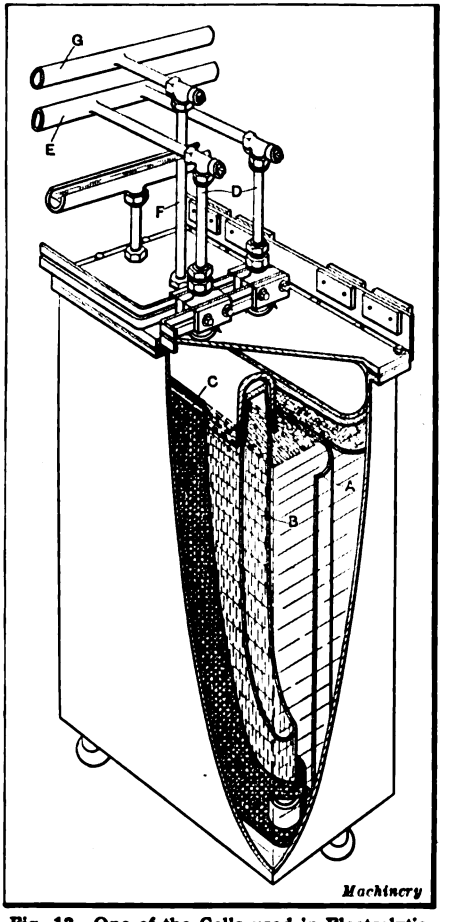


**Fig. 13. One of the Cells used in Electrolytic Oxygen Manufacture**

In the manufacture of oxygen by this method, the electrolyzer in which the dissociation of the hydrogen and oxygen takes place is so arranged that the two gases are kept separate from each other and carried off through individual pipes. Fig. 13 shows the arrangement of the type of electrolytic cell made by the Davis-Bournonville Co. The reservoir in which the potassium-hydroxide solution is contained is divided by a metal plate *A;* and an anode *B*, on which the oxygen is formed, is suspended in the solution on each side of the partition. The

cell itself is made of metal, and the container and metal partition form the cathode or negative pole from which hydrogen is evolved. To provide for keeping the oxygen and hydrogen separate, an asbestos curtain *C* surrounds each of the anodes *B;* this curtain extends almost to the top of the cell and keeps the oxygen separate from the hydrogen. The oxygen gas is carried off through the two pipes *D* which are connected with the off-take

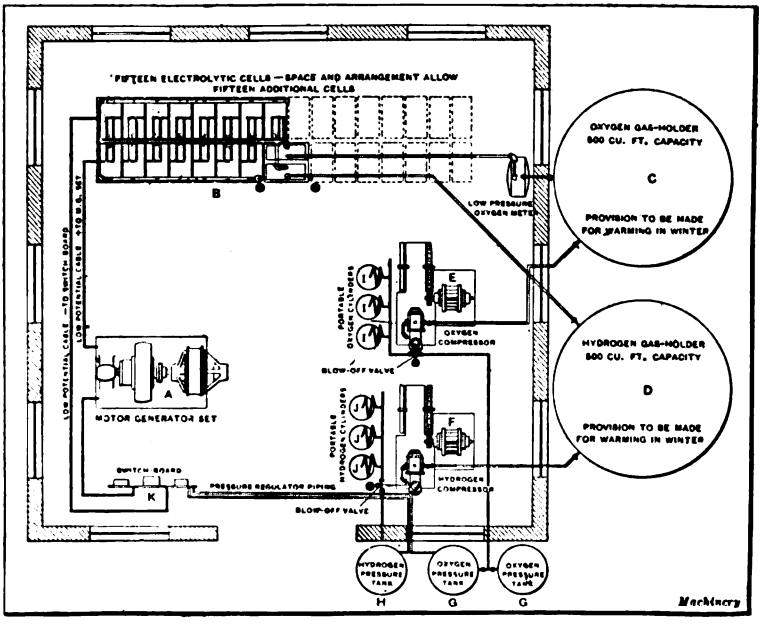


**Fig. 14. Plan of Electrolytic Oxygen Plant**

pipe *E*, that carries the oxygen from all of the cells to the gasholder in which it is collected. Similarly, the hydrogen is carried off from the cell through pipe *F*, which is connected with pipe *G* that carries the hydrogen from all of the cells.

When the electric current is passed through the cell, the entire volume of water is placed in a state of charge, which results in the liberation of oxygen at the anode and hydrogen at the cathode. There is no tendency for these gases to be liberated at any point except at their respective terminals in

the cell, and so the asbestos separator *C* will keep the two gases from mixing. It is important, however, for the pressure of the oxygen and hydrogen to be kept the same, in order to avoid the tendency for the gas at higher pressure to be forced through the asbestos curtain. This equalization of the pressure is provided for by having the two pipes *E* and *G* pass the gas which they carry through two water seals. These are arranged so that the pressure head of water is the same in each seal, and, as a result, the back pressure exerted on the oxygen and hydrogen leaving the cells is maintained exactly the same. Some factories make a practice of collecting the hydrogen gas which is generated, for use in oxy-hydric cutting torches; and, in certain cases, the hydrogen has been employed for filling the bulbs of incandescent electric lights. In many shops, however, it is not found worth while to attempt to utilize the hydrogen, and in such cases this gas is allowed to pass off into the atmosphere.

**Complete Plant for Electrolytic Oxygen Production.** — Fig. 14 shows the arrangement of a complete plant for the generation of oxygen and hydrogen by the electrolytic method, in which provision is made for collecting both the oxygen and hydrogen. In this illustration the motor generator which supplies current to the electrolytic cells is shown at *A*. The cells are shown at *B;* the gas-holders for the oxygen and hydrogen, at *C* and *D*, respectively; the compressors for compressing the oxygen and hydrogen, at *E* and *F;* and the pressure tanks to which the compressors deliver the oxygen and hydrogen, at *G* and *H*. It will also be noted that provision is made for connecting portable cylinders *I* and *J* direct to the compressors so that these cylinders may be filled with oxygen and hydrogen.

In presenting a description of the operation of the plant, it will simplify matters to refer only to the equipment used for the generation and compression of the oxygen. The equipment shown for handling the hydrogen works on exactly the same principle, so that one description will apply in both cases. Upon leaving the electrolytic cells *B*, the oxygen is passed along to the gas-holder *C*, which is of the standard type, in which an inverted bell is suspended over water by means of a counter-

weight. As the oxygen enters the gas-holder, the bell rises, and when it has reached a predetermined limit — or when the gas-holder is filled to its capacity — an automatic switch is thrown which starts the electric motor that drives the oxygen compressor *E*. This results in pumping oxygen out of the gas-holder and compressing it in the oxygen pressure tanks *G*. These tanks are usually arranged for a maximum pressure of 300 pounds per square inch, and, when this has been obtained, a pressure regulator of the Bourdon spring type, which is located on the switchboard *K*, throws a relay that, in turn, trips the compressor motor switch and stops the compressor.

While the compressor is in action, it will be evident that oxygen is being withdrawn from the gas-holder *C*, with the result that the bell descends; and when the bell has reached the lower limit of its travel — so that practically all of the oxygen has been pumped out of the holder — an independent electric switch will be thrown to stop the compressor motor. When the compressor is stopped in this way, the motor generator *A* continues to run so that the supply of oxygen from the electrolytic cells *B* is continued until the gas-holder *C* is filled to its capacity. When this result is obtained, the normal sequence of events would be for the switch which governs the compressor motor to be thrown over, in order to start the compressor. It may happen, however, that the pressure in the oxygen tanks *G* is at the maximum of 300 pounds per square inch; when such is the case, means are provided to make it impossible for the switch to be thrown to start the compressor motor. Under such conditions, an automatic switch is thrown, which stops the motor generator and cuts off the generation of oxygen in the electrolytic cells. As soon as the oxygen in the pressure tanks has been partially consumed, thus lowering the pressure, the compressor motor automatically starts to deliver more oxygen to the pressure tanks, with the result that the gas-holder starts to descend. This, in turn, closes the switch controlling the motor-generator set, which restarts the motor-generator and causes the electrolytic cells to begin to generate more oxygen. The 500-ampere cell requires $1\frac{1}{4}$ gallon of water to be added each

twenty-four hours, and the 1000-ampere cell requires $2\frac{1}{2}$ gallons of water per twenty-four hours; otherwise the only attention necessary is the maintenance of the different units of the plant in running order, and this takes very little time. The purity of the oxygen generated by this process is in excess of 99 per cent.

**Influence of Impurities in Oxygen.** — It is of considerable importance that the oxygen should be as pure as possible. The impurities which decrease efficiency are nitrogen or hydrogen. When oxygen is prepared by the liquid-air process, a certain percentage of nitrogen is always certain to be present; nitrogen tends to cool the heating flame. In the manufacture of oxygen by the electrolytic process, the only impurity is hydrogen. The effects of the presence of nitrogen are especially noticeable when cutting operations are done by the oxy-acetylene or oxy-hydrogen torch. Experiments have been carried out in order to determine just how serious the effect of nitrogen in oxygen is. These experiments show that the purity of oxygen plays a most important part in the efficiency with which the cutting operations may be accomplished. With oxygen about 85 per cent pure, it requires three times as long to cut a plate an inch thick as when the oxygen is 99 per cent pure. Even the one-half of one per cent drop from 99 per cent oxygen to 98.5 per cent quality means a decrease in efficiency of 16 per cent. Hence, even if the better grade of oxygen costs somewhat more, it is apparent that it must cost a great deal more in order that it should be more expensive to use than the cheaper grades. It is, therefore, essential to obtain oxygen as free as possible from nitrogen; but the adverse effects of hydrogen on cutting work are practically negligible.

**Acetylene.** — Acetylene has been known for a great number of years, having been discovered in 1836, but until 1892 its production was merely a laboratory experiment. In that year calcium carbide was accidentally manufactured in an electric furnace at the works of the Willson Aluminum Co., in North Carolina. It was considered of no value and was thrown into the river. It was then accidentally discovered that the gas arising from it when thrown into water would ignite, and a

further investigation proved that this was acetylene. Its commercial exploitation began shortly afterward in its use for isolated lighting plants, as in a suitable burner it produces an intensely white and very pleasing flame; and, as the generation is comparatively easy and safe, it has attained a wide popularity.

Acetylene is composed entirely of carbon and hydrogen, both of which elements, when combined with oxygen, burn, producing heat. Acetylene has the property, if completely burned, of

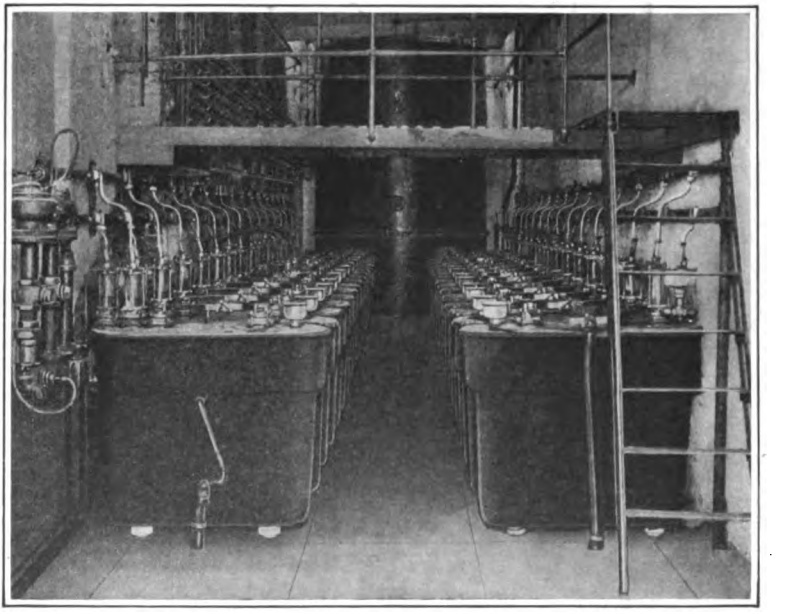

**Fig. 15. International Oxygen Co.'s Apparatus for Making Oxygen**

producing the maximum temperature possible in a gas flame. This was appreciated by a number of experimenters, but they found great danger from its explosive properties. For instance, if mixed with air and compressed to about 30 pounds' gage pressure, it explodes. Even if not mixed with air it cannot be compressed above this pressure and subjected to heat, shock, or other disturbances without being decomposed into its elements; and then a violent explosion results. This is one reason why acetylene generators must be properly designed and taken care

of; also, to prevent overheating, a large excess of water should be used, as one pound of carbide will raise the temperature of one gallon of water 90 degrees F.

**Acetone for Storing Acetylene.** — It has been found, however, that certain liquids have the peculiar property of absorbing many volumes of acetylene. The most satisfactory liquid for this purpose is acetone, and this is used in all compressed acetylene tanks at the present time. It is also found advantageous and safer to fill these cylinders completely full of asbestos or other porous material, so that there will be no chance of dead spaces which might otherwise become filled with air and make the cylinders more or less unsafe. In this porous material is contained the acetone, and in the acetone is dissolved the acetylene. It is perfectly safe to store compressed acetylene in such tanks, and they have been subjected to the most violent shocks, such as firing a rifle bullet through them, dropping large weights on them, and even putting them into hot fires, without explosion; but the actual process of compressing the acetylene in the tanks is still accompanied by danger, if attempted by inexperienced men. It should be done only by those who thoroughly understand this work, and the nature of acetylene. Hence no attempt should be made to transfer acetylene from one tank to another, as has been sometimes suggested. Acetylene may also be produced in a generator suitable for the purpose by bringing in contact water and calcium carbide. This produces gas more cheaply than that furnished in tanks, and, if the generator is of the proper design, it will be found entirely satisfactory for most welding.

**Generating Acetylene Gas.** — When calcium carbide is brought into contact with water, acetylene is given off and slaked lime left as a residue. There are three kinds of generators, the essential differences being the methods of uniting the carbide and the water. These methods are:

1. Dropping the carbide into a large body of water.
2. Allowing the water to rise slowly against the carbide.
3. Dropping the water on the carbide.

The first is by far the safest method; it keeps the pressure uniform, gives cooler and purer gas, and is in every way to be

preferred. In any case, the directions furnished by the makers of the generator should be strictly followed, or an explosion may result. The safety valve should be tested daily to be sure that it is working properly; the regulator should be kept in condition so that the working pressure will be kept within proper limits; leaks of all kinds should be carefully avoided; and the feeding mechanism should be stopped, and the cut-out valve in the supply pipe shut off every night or when the generator is out of service for any length of time. Keep flames or lights of any kind away. An excess of caution is advisable in handling acetylene, and the matter of insurance should receive special attention, as improper location or installation may invalidate any insurance in force. If the generator is worked too hard it will become hot, and in this condition is dangerous. The maker can say how many torches of a given size should be connected and working at one time. If a generator becomes hot for any reason, stop the use and generation of gas until it is cooled down, no matter how long it takes.

**Precautions in the Use of Acetylene Generators.** — A generator containing carbide should never be moved around; it is liable to be upset, and the water, coming suddenly in contact with a large quantity of the carbide, will raise the pressure to the explosive point, which is about 30 pounds per square inch when acetylene has any air mixed with it. Fatal accidents have occurred from this. Freezing must be guarded against, but, if thawing out is necessary, hot water applied externally is the only safe method to use. Where flash-back chambers are provided, keep them in proper condition, filling them with water every time carbide is put in. If any part of the generator is not understood by the user, consult the manufacturers; they will give full instructions and advice.

The end of the discharge pipe for the residue should be where it can be seen, so that if there is a loss of water, due to a leaky valve, it can be noticed. If water is gradually lost, it may in time entirely drain out, and the generator will run hot. It will not give a sufficient or uniform supply of gas and will be in a dangerous condition. Do not open the hand-hole, or any open-

ing in the body of the generator, under such conditions, as it is liable to produce an explosion. Let the generator cool down until it reaches the room temperature. The proper method of handling depends upon the type of generator, and if one is not sure what to do, he should consult the manufacturer. Explosions will never occur if the generator is watched and handled in the proper way.

**Types of Generators.** — There are two general types of acetylene generators used in the United States, which are called high- or medium- and low-pressure, respectively. The first uses acetylene under a pressure as high as 6 pounds per square inch at the torch, while the other uses a pressure of only about as many ounces. The torches for these two systems are entirely different in construction, and must be handled differently in operation. Care must be taken to follow the instructions of the manufacturers in regard to their operation in every case or satisfactory results will not be obtained.

**Impurities in Calcium Carbide.** — Calcium carbide, being made of coal, or coke, and lime by heating them together in an electric furnace, naturally contains some of the impurities in these substances. Neither coal nor coke is free from sulphur, nor is lime entirely free from phosphorus; therefore, acetylene made in a generator will contain more or less sulphuretted hydrogen and phosphoretted hydrogen, the amount depending upon the purity of the original materials. These impurities, and the exceedingly fine dust that is sometimes carried over with the gas, give to the welding flame a somewhat yellow color which is not noticed when dissolved acetylene is used, the flame then having a slight violet tinge.

The presence of these sulphur and phosphorus compounds can be shown by a very simple test. Moisten a piece of white blotting paper with a 10-per-cent solution of nitrate of silver and turn a jet of acetylene on it. If these gases are present, the moistened spot will turn black, and a rough idea may be obtained of the amount of the impurities by the rapidity with which the action takes place. Inasmuch as both sulphur and phosphorus, when present in more than very slight amounts, are

injurious to iron and steel, it is necessary to provide for the removal of these gases from acetylene, if important welds are to be made. The importance of purifying generator acetylene is not realized in this country, although both in England and on the Continent purifiers are in quite general use. They are of comparatively simple construction, and it is believed that it is only a question of time until their use will be general in the United States. On the other hand, however, the carbide made

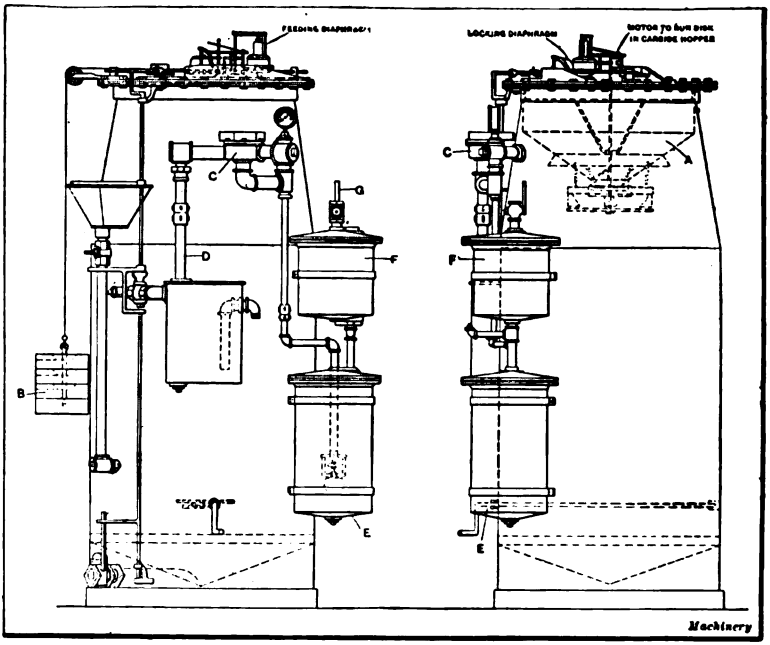


**Fig. 16. Davis-Bournonville Acetylene Generator**

in the United States is more free from sulphur and phosphorus compounds than that made abroad. Sulphur and phosphorus compounds are not so injurious to other metals as to iron or steel, and, as the quantities are small when good carbide is used, ordinary work is not seriously damaged.

The dust carried over with the gas, in certain types of generators, consists very largely of lime, which has an exceedingly injurious effect on any steel or iron weld. A yellow deposit on

the lime residue may indicate that the generator has been working at too high a temperature, and, possibly, a dangerous one. It is not often that this is found.

**Design of Generators for Acetylene Gas.** — Fig. 16 shows the form of generator developed by the Davis-Bournonville Co. for use with its positive-pressure (often erroneously referred to as high-pressure) torches. In this generator the carbide is introduced into the hopper *A* through two filling holes at the top of the generator. As acetylene is an extremely inflammable gas, it must be handled with considerable care. The operation of acetylene generators has been made the subject of careful study in the laboratories of the fire underwriters. At present the rules of the insurance companies require a generator to be operated under such conditions that the gas will be produced at the rate of 1 cubic foot per pound of carbide per hour. As a result, means must be provided for dropping the calcium carbide from the hopper *A* into the water in the generator at a prescribed rate. This is accomplished by means of a clock motor which is driven by the counterweight *B*. This motor causes the rotation of a disk at the bottom of the hopper, and as the disk revolves the carbide is swept off by an inclined plate or vane.

With acetylene gas under pressure of more than two atmospheres — approximately 30 pounds per inch — there is danger of endothermic explosion; and, to provide an adequate margin of safety, the pressure of the gas in the generator is not allowed to exceed 15 pounds per square inch. When the pressure reaches 15 pounds per square inch, the first one of these two diaphragms is distended, with the result that a locking device stops the clock motor and, hence, cuts off the supply of calcium carbide. As a safety device, a second flexible diaphragm is provided which operates at a pressure slightly above 15 pounds per square inch. In case the first diaphragm should fail to work, the second one would rise and engage a locking clutch which stops the motor. In addition, a safety valve is provided at *C* which will blow off in the event of the pressure rising above the required point. This safety valve is connected to a pipe which extends up above the roof of the generating house so that the acetylene may be

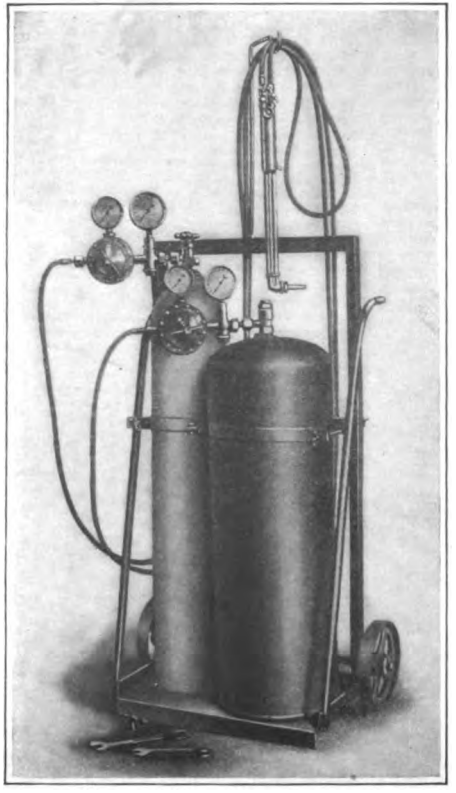

Fig. 17. Portable Compressed Acetylene and Oxygen Tanks

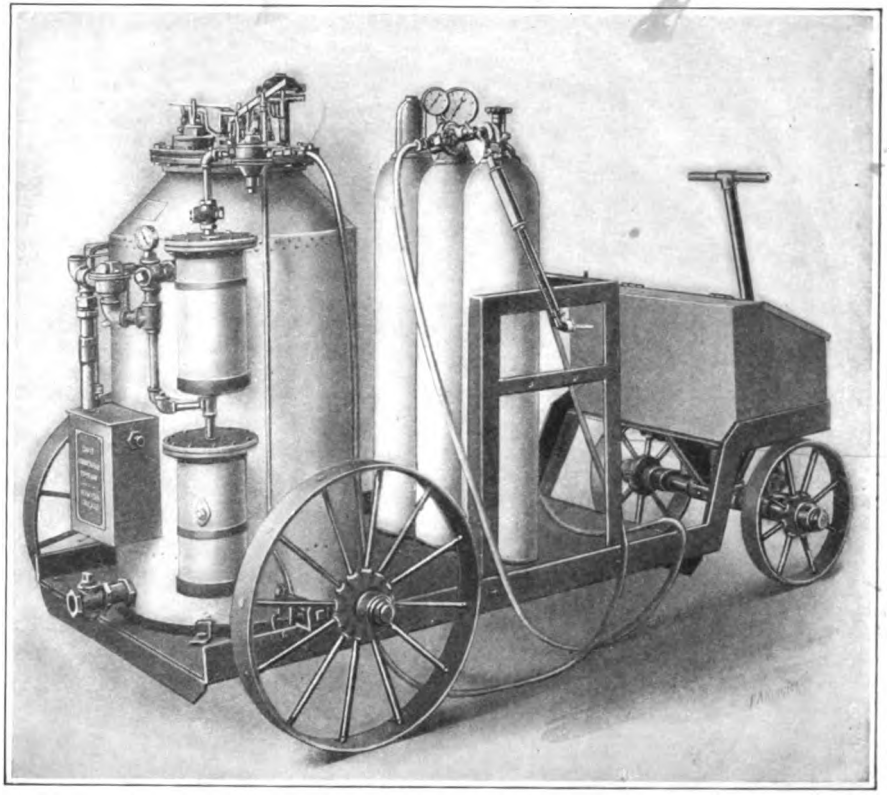

Fig. 18. Portable Outfit comprising Acetylene Generator and Oxygen Tanks

discharged into the atmosphere. In this way, all danger of explosion is eliminated.

Lump carbide, designated as the $1\frac{1}{4}$ by $\frac{3}{8}$ inch size, is used in the generator. When this carbide is dropped from the hopper, it sinks to the bottom of the water in the generator, and, as a result, the acetylene gas which is liberated must rise through the full depth of water. Two advantages are secured in this way: first, the acetylene receives a preliminary washing in the generator; and second, the heat produced by the chemical reaction of the carbide with the water is absorbed by the water so that the gas is passed on at a relatively low temperature. Upon leaving the generator, the gas passes into the pipe *D*, which carries it to the bottom of the flash-back chamber *E*. This chamber is full of water and serves the double purpose of giving the gas a second washing and forming a water seal between the service pipe and the acetylene in the generator. After passing through the flash-back chamber, the gas enters the filter *F*, which is filled with mineral wool that serves to remove suspended impurities, and upon leaving this chamber the gas enters the service pipe *G*, from which connection is made direct to the torches. It is not within the scope of this treatise to give instructions regarding the operation of the acetylene generator, but the manufacturers issue a booklet in which complete information is given in regard to this branch of the welding and cutting industry.

The generators are made in five sizes, with capacities for charges of 25, 50, 100, 200, and 300 pounds, respectively. One pound of carbide will produce $4\frac{1}{2}$ cubic feet of acetylene, so that the different sizes of generators will produce 112, 225, 450, 900, and 1350 cubic feet of acetylene from a single charge. These generators are intended for use in shops where the acetylene is used direct from the generator, but the Davis-Bournonville Co. also makes a generator known as the "Navy" type, which is designed for use in connection with a compression plant for collecting the acetylene in cylinders for portable use, and acetylene can also be taken direct from the generator under pressure for use in the cutting and welding torches. In this type of

plant provision is made for drying the acetylene and removing the air from it preparatory to compression.

**Portable Generators.** — The generators which have just been described are made for installation in a fixed position, but for some classes of work it is desirable to be able to move the source of acetylene about from place to place. To meet this require-

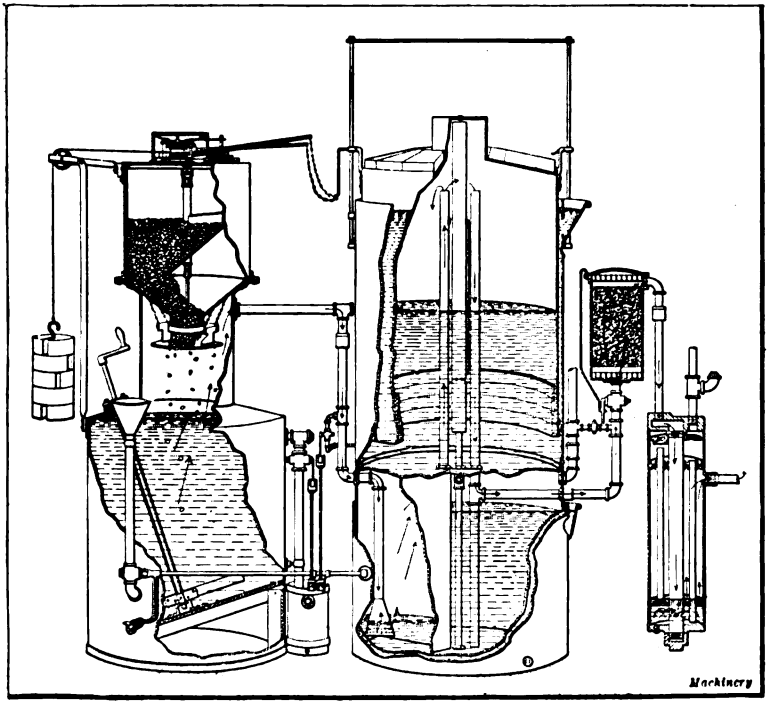


**Fig. 19. Oxweld Low-pressure Acetylene Generator**

ment, portable outfits, as shown in Figs. 17 and 18, are made. In one of these a two-wheeled truck is employed, on which are mounted an oxygen cylinder and a cylinder containing the acetylene gas. In the other style of portable outfit an acetylene generator and a battery of oxygen cylinders are mounted on a four-wheeled truck. This equipment is made with either the 25- or 50-pound acetylene generator, and with a corresponding number of oxygen cylinders, according to the requirements of

the plant in which it is to be used. It is often found convenient to use one of these portable outfits in order to avoid the necessity of moving heavy work, or for working in different places in large factories, where it is easier to take the torch to the work than to bring the work to the torch.

Fig. 19 shows the generator furnished by the Oxweld Acetylene Co. This is a low-pressure generator, used in connection with the company's low-pressure torch. The illustration, with the arrows indicating the flow of the gas, shows clearly the action of the generator. The apparatus to the left is the generator proper, while that to the right is the gasometer which is used for storing the gas at low pressure.

**British Types of Acetylene Generators.** — Fig. 20 shows the form of generator developed by the Thorn & Hoddle Acetylene Co. It is of the water-to-carbide type and is made in three different patterns. The generator consists of a main water tank in which floats a gas-holder guided by standards. The generating chambers are surrounded by a large body of water and the gas is generated at a low temperature. The supply of water is automatic, the rising and falling of the gas bell closing and opening a ball valve controlling the water supply. The larger sizes of generators have two or three generating chambers, and the water supply valves are so arranged that only one chamber comes into action at a time, but, when this is exhausted, another chamber comes into action without loss of gas or stoppage of work, and the exhausted chamber may be safely recharged. An indicator placed outside the generator shows the generating chamber in use. The gas is efficiently washed, and the carbide containers are so constructed that the water does not drip onto the carbide, but rises towards it. The carbide used in the generators is "lump," designated as 1 to 2½ inches or larger. The gas-holders and water tanks are constructed of strong galvanized steel.

The generators are made in six sizes, with capacities for charges of 6, 9, 15, 35, 50, and 75 pounds, respectively. The approximate acetylene output of the different sizes is 27, 42, 70, 160, 230, and 350 cubic feet from a single charge. The gen-

erators are made for fixed installations, or, as it is desirable in some classes of work to move the acetylene source from place to place, portable. The portable equipment is made with either the 9, 15, 35, 50, or 75 pounds' generator.

Fig. 21 shows a generator furnished by the Sirius Autogenous Co. This is a carbide-to-water generator. The plant comprises

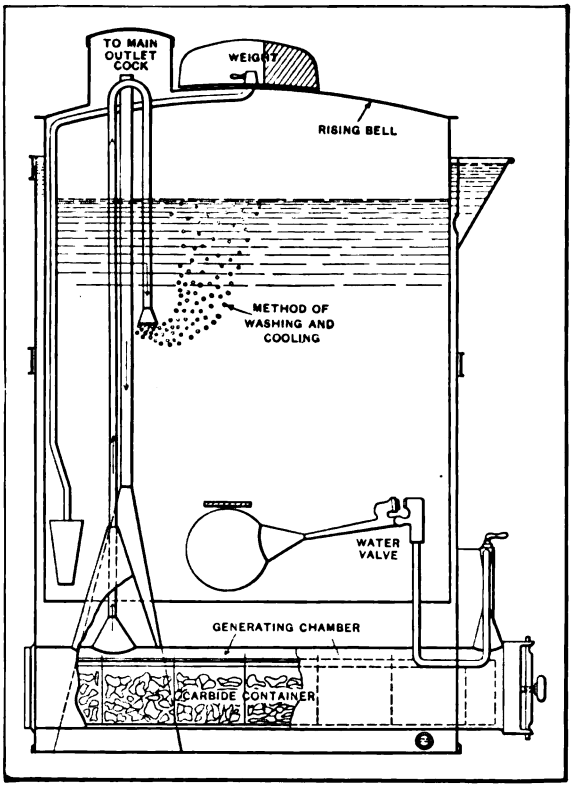


**Fig. 20. The "Incanto" Acetylene Generator**

the following parts: Generator, condenser, washer, gasometer, and purifier. The generator consists of a cylindrical chamber, the upper portion containing the carbide magazine and automatic feed mechanism, the lower portion containing the generating water. The carbide is distributed by a bucket wheel, which may be automatically rotated by the falling of the gasometer bell.

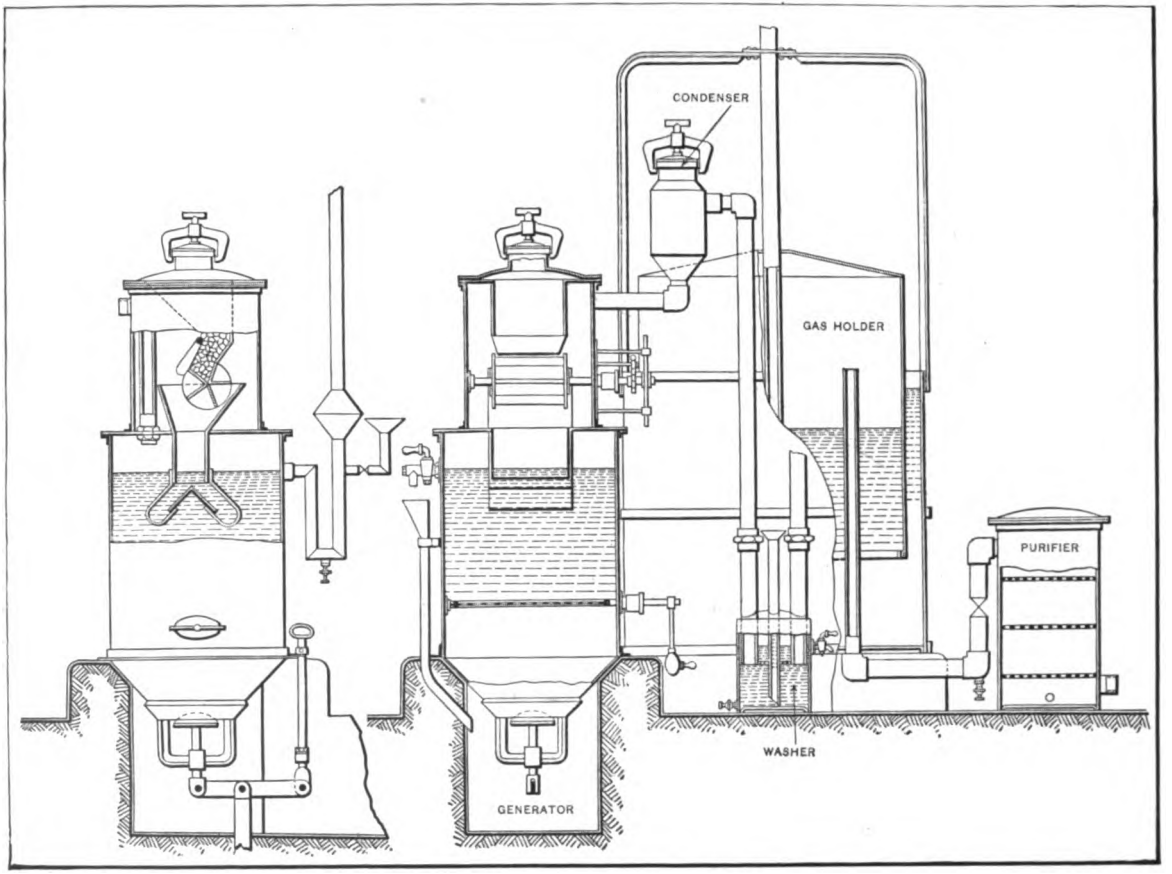


**Fig. 21. Sirius Autogenous Co. Carbide-to-water Generator**

The condenser is provided to intercept humidity. The washer serves to absorb certain impurities and also to prevent the gas returning from the gasometer to the generator. A purifier and filter are provided to deal with the chemical impurities and solid particles. The illustration shows clearly the action of the generator.

**Hydrogen Gas.** — Instead of using oxygen and acetylene, oxygen and hydrogen are the gases frequently used when cutting metals. In fact, for the cutting of very thick steel, hydrogen is far superior to acetylene, because of the much longer flame of hydrogen. This gas is obtained when water is decomposed by electrolysis, there being two parts of hydrogen to one part of oxygen. The gas is actually formed as a by-product in the production of oxygen by the electrolytic method. It is highly inflammable and produces a heat of about 4100 degrees F. when burned with oxygen. In cutting steel, it leaves a comparatively smooth surface, the metal being but little affected by oxidization on either side of the cut. For rapid and economic welding the oxy-acetylene flame is far superior to the oxy-hydrogen flame, but, for cutting especially thick metal, the hydrogen flame is, as mentioned, preferable.

For welding, hydrogen is only used in localities where oxygen is electrolytically produced and the hydrogen is thus a by-product. Practical experience indicates that oxy-hydrogen welding is suitable for thin sheet work only. The temperature of the flame is not sufficiently high to permit the welding of thick plates or castings, since the flame must be applied for so long a period before the necessary fusion temperature is reached, that the metal operated upon deteriorates. For thin sheet welding, the process has certain advantages, however, as the flame is more diffused than the oxy-acetylene flame, and, consequently, less liable to melt through or pierce the metal, as sometimes occurs when the oxy-acetylene flame is employed on thin work. In fact, it is stated by some welders that a better-looking and more highly finished job can be made with the oxy-hydrogen flame on sheets $\frac{1}{16}$ inch and less in thickness, than by any other process of welding. Even at best, however, the quality of the

weld is uncertain, and unless hydrogen is produced as a by-product its use is expensive.

**City Gas for Welding.** — Owing to the impurities present in ordinary city gas, it cannot be employed for welding in any case where the strength of the weld is of importance. The flame temperature is also considerably lower than the oxy-hydrogen flame; hence, this kind of gas can be used only on very thin iron or steel sheets, or on metals having very low melting points. It is not used except in very special cases. There are a number of other gases which will burn when mixed with oxygen, such as Pintsch gas, Blau-gas, etc., but none of these will produce as high a flame temperature as acetylene.

**Piping.** — Acetylene piping should be carefully designed, especially in regard to size. Frequently trouble is caused, particularly in the case of low-pressure systems, by having the pipe too small. The manufacturers of the equipment will give advice in this connection. Acetylene piping can be put together with ordinary screw joints and pipe grease; or other lubricants, such as red or white lead, may be used. It is better, however, to weld the pipe and insure in this way against leakage. In the case of oxygen piping, no grease or oil whatever should be used, if it is put together with screw joints. A lubricant should not be depended upon to make a pipe joint in any case, but only to allow the threads to be easily screwed into place; the joint should depend on the threads. Soap answers the purpose for oxygen pipe very well. It is, however, advisable, as in the case of acetylene piping, to weld the joints. Piping for both oxygen and acetylene should be galvanized. The ends of all pipes should be reamed out to make the pipe of uniform size throughout. Where piping is welded, no fittings should be used. Valves should be of the best quality and of sufficiently large area, particularly with a low-pressure system, to avoid reducing the pressure. After the piping is all erected, it should be tested to at least 100 pounds' pressure per square inch, and leaks, if any, stopped. The best method of testing is with soapsuds, brushed not only on the joints, but all over the pipe, as there are sometimes pin holes or slight defects in the body of the pipe.

**Acetylene and Oxygen Tanks.** — Portable acetylene tanks are provided by the makers of acetylene gas, from whom they may be obtained on reasonable terms. The cost of the gas is about two and one-half times that made in a generator, but this expense is warranted in some cases even for shop work, on account of the tanks costing less than the generator. Each case has to be considered separately. The larger the shop, the greater is the advantage in the use of a generator. The charging pressure of these tanks is about 225 pounds per square inch, but this varies so much with the temperature that the pressure alone is no indication of the amount of gas in the tank. It is sometimes found that, after working an hour or so, the pressure is equal to or greater than that at the start, due to the tank being warmer. Tanks should be kept in a cool place and the outlet capped to be sure that there is no chance for a leak.

Compressed acetylene should never be used at a greater rate per hour than one-seventh of the capacity of the tank. For instance, if a tank holds 300 cubic feet, 45 cubic feet per hour is about the maximum rate at which the acetylene should be drawn. If it is necessary to use a torch large enough to exceed this rate, two or more tanks should be coupled together with manifolds, which can be procured from the manufacturers of the tanks or made in any good machine shop. A greater rate of discharge than that stated above results in some of the acetone being drawn out, which is liable to cause bad welds.

The Federal law requires that, in shipping a tank containing oxygen, or a full acetylene tank, a label be pasted on it, colored green or red, respectively, and worded according to the instructions on the subject issued by the Bureau of Explosives, 30 Vesey St., New York City, from which copies may be obtained. Empty oxygen tanks need no label, but the bill of lading or express receipt should specify that the tanks are empty, in order to obtain the advantage of the lower freight rate. Empty acetylene tanks must have the red label removed before shipment and can only be shipped by freight. Any tank found to be defective should be tagged and the manufacturers notified by letter. It occasionally happens that a valve cannot be shut. Such a matter

should be reported to the manufacturers, and, if the valve is found defective, they will make an adjustment for the amount of gas lost. All tanks, both oxygen and acetylene, are provided with safety disks or plugs. These are intended to prevent excessive pressure caused by heat or otherwise, by allowing the gas to escape gradually and thus prevent an explosion. In some cases these safety devices are so arranged that they are sealed to prevent tampering with them. If this seal is broken, no adjustment will be made. Therefore, if anything goes wrong with the valve or disk, do not attempt to repair it, but return it in exactly the condition in which it was found. Of course, if an acetylene tank should leak, it should be placed out of doors to avoid danger of explosion. The percentage of such difficulties is exceedingly small.

**Machine Tool Equipment for Welding Shops.** — The machine tool equipment to be provided will depend upon circumstances. For a shop where welding alone is done, the following should be provided: 24-inch upright drill; floor stand; two-spindle emery wheel for 10-inch wheels; flexible shaft grinder with 6-inch wheel. These tools can be driven by a small electric motor, if current is available. Any other motive power can be used, although a gasoline engine should be carefully installed in order to avoid fire risk. It is best not to permit gasoline in the shop under any pretext whatever.

For a large shop, or where a good machine shop is not available, it may be necessary to install more machinery. The following additional tools will cover practically everything necessary: lathe, 20-inch swing, 4 feet between centers; lathe, 30-inch swing, 8 feet between centers; planer, 36 by 36 inch by 6 feet; pillar shaper, 12-inch stroke; horizontal boring mill, 4 feet between heads; 3-foot plain radial drill. These tools must be accurate, but, as there is no question of production in quantity involved, they may be of light and simple construction; for instance, it is not necessary to have quick change-gears on the lathes. All such expense should be avoided. Careful consideration should be given to the machine tool equipment. It is expensive, and, unless enough work is done, it will not pay

to install it, but it will be cheaper to do the work with hand tools, or even send it to a shop at some distance.

The real cost of operating a machine is frequently underestimated. Interest, depreciation, repairs, insurance, and taxes have to be paid, even if not charged in the operating expenses. Taking the sum of these items at 15 per cent per year on the cost of a machine, and assuming the installed cost at $2000, there will be a monthly expense of $25 against the machine. If it is operated 200 hours per month, the hourly expense will be 12½ cents; if it is used only 20 hours per month, the hourly expense will be $1.25. It is evident that no ordinary charge for work, say 60 or 75 cents per hour, will cover the latter expense, which is exclusive of labor, power, and supplies. Each case is a law in itself, and all that is urged is that careful and intelligent consideration be given, so as to avoid financial loss.

**Other Equipment.** — It is generally necessary to heat pieces before welding, to obtain a sound weld, as well as to economize in the gases. For this purpose, plain blacksmith forges are the most convenient for small work. The tuyere should be level with the bottom of the pan, which should be of cast iron. The pan should measure about 23 by 36 inches inside and about 4 inches deep, which will allow the bottom to be lined with 1-inch thick firebrick, laid in fireclay, and still leave the sides high enough to keep the fire off the floor. The simplest fan drive is good enough, as it is never used except in starting the fire. It is well to have plenty of forges, as a good welder on moderate-sized work can keep two or three busy without any difficulty.

*Floors.* — For heavy work a concrete or brick floor is necessary; this, if of concrete, should be at least 6 inches thick, laid on a solid foundation of cinders that should be free from coal and well rammed; and proper provision should be made for drainage. The concrete may be a rather lean mixture, but should have a top dressing ½ inch thick of a rich cement mortar. The floor should be about 10 by 15 feet or 12 by 12 feet, preferably the former, as it is more convenient for a number of fires.

*Hoists.* — Over the floor should be some kind of hoist of a capacity of about 3 tons, which will handle almost any work

that can be brought into the shop. The kind of hoist depends upon the circumstances, such as the construction of the building, space around the floor, etc. A jib crane is very convenient, but expensive. If the roof trusses are strong enough, an I-beam extending between them and carrying a trolley and chain hoist is ample and cheap.

*Provision for Building Preheating Fires.* — If the floor of the building is of concrete, be sure that it is heavy enough to

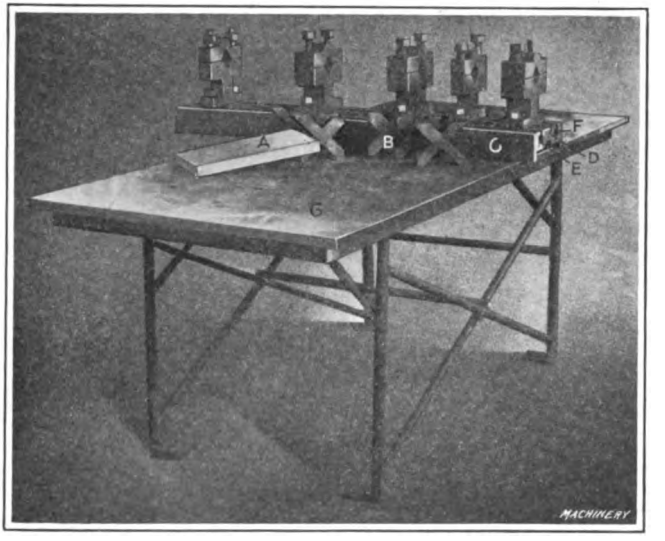


**Fig. 22. Welding Table, Welding Jig, and V-blocks**

stand considerable heat. Of course, a fire should never be built directly on the concrete. A layer of firebrick can be placed under the entire area to be covered by the fire, and the piece laid on this raised enough to get the fire in place; or plates of cast iron or steel can be laid on bricks to give air space underneath and the fire built on the plates. Cast-iron plates 1 by 3 feet are best. They should have 1-inch holes cored in them about 6 inches apart for draft, and, when setting up, they should be left slightly apart for the same reason. Angle-plates of the same general design may be used for walls instead of bricks, and in some cases are very convenient. They should not have any holes in them.

They radiate more heat than bricks, but do not fall over so easily. Some of them should be 18 inches long for small fires. Firebrick will also be needed for holding the fires in place on the forges, and for use on the floor. Hard-burned brick, while not so good for the regular purposes for which firebrick is used, is better for this purpose, as it does not break or chip so easily in handling.

**Welding Table.** — Fig. 22 shows a cast-iron table 30 inches wide and 72 inches long. It is planed on the top, bottom, and all

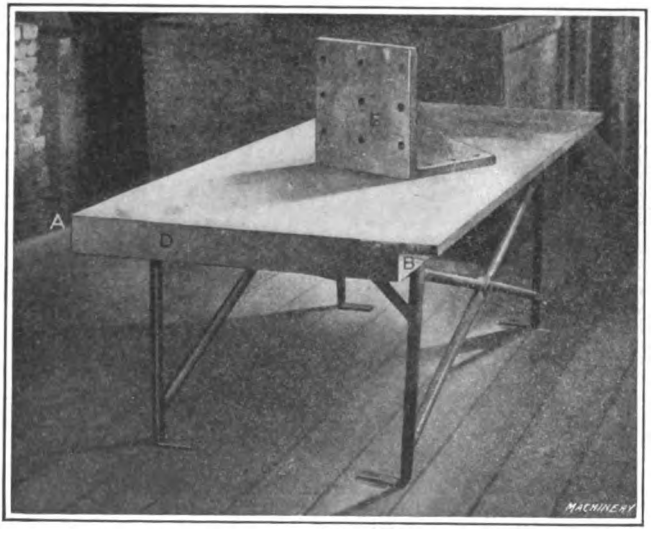


**Fig. 23. Another View of Welding Table and Angle-plate**

edges, and has a support made of old $\frac{3}{4}$-inch pipe welded together. It is 26 inches high from the floor, which is found to be most convenient, as small work can be done by the welder while sitting; and for large work, such as rear axles, rear-axle housings, cylinders, etc., which have to be tested, and which are frequently set up high on blocking, it is not too high for convenience. Another view of the table is shown in Fig. 23, which also shows an angle-plate that is very convenient. It will be noticed that the rib *D*, which is $\frac{3}{4}$ inch thick, extends on two sides of the table, while the other two sides are provided with a flange *B*. As

stated, all of these edges are planed. This permits of clamping pieces vertically or horizontally, as the case may be, and has been found to be an exceedingly convenient arrangement.

**Jigs and V-blocks.** — Fig. 22 also shows what was originally designed as a jig for welding crankshafts, although it has been found that it is a valuable appliance for many other purposes, particularly in welding bars, tubing, etc., that must be kept straight. It is shown at *C*. The V-blocks are provided with tongues which slide in the groove *D;* the slots *E* and *F* are at unequal distances from the groove. This is done to insure proper setting of the V-blocks. The base is planed on the top and bottom, and after the bases of the V-blocks were machined they were bolted in place and the V's in the top of them planed

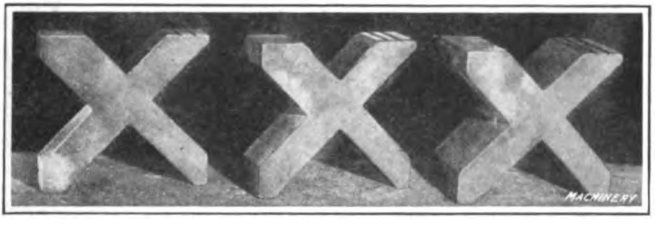

**Fig. 24. Set of Cast-iron V-blocks of Different Thicknesses**

at the same time to insure absolute alignment. The V-block caps have the holes for the studs drilled $\frac{1}{8}$ inch large, so that there will be no difficulty in clamping when screwed down on a round piece. The base of this jig is 10 inches wide and 36 inches long. The V-blocks are of different thicknesses, the wide ones being $2\frac{1}{2}$ inches and the narrow ones $1\frac{1}{2}$ inch. This permits of getting into corners, which is sometimes desirable. There are also shown a plate of graphite at *A* and a set of ordinary V-blocks at *B*, which are better shown in Fig. 24. Two sets of these are useful for holding shafts and similar pieces that must be kept straight in welding, and will be found of advantage for many other purposes. The six V-blocks should be made from one casting, first planed and then cut off to the required thickness. Each one of a pair should be planed to the same thickness, and the 1- and $1\frac{1}{2}$-inch sizes together should have the same thick-

ness as the $2\frac{1}{2}$-inch size. The grooves should be planed in the casting before cutting off, to enable the blocks to be placed in the same line as when originally planed, it being difficult otherwise to plane the V's exactly symmetrical. The various devices shown in these two illustrations make it possible to take care of almost any shape that must be kept square or in line.

A kerosene-oil burner can, in many cases, be used for heating large articles in which contraction strains will not cause any trouble, and is useful to have in a welding shop.

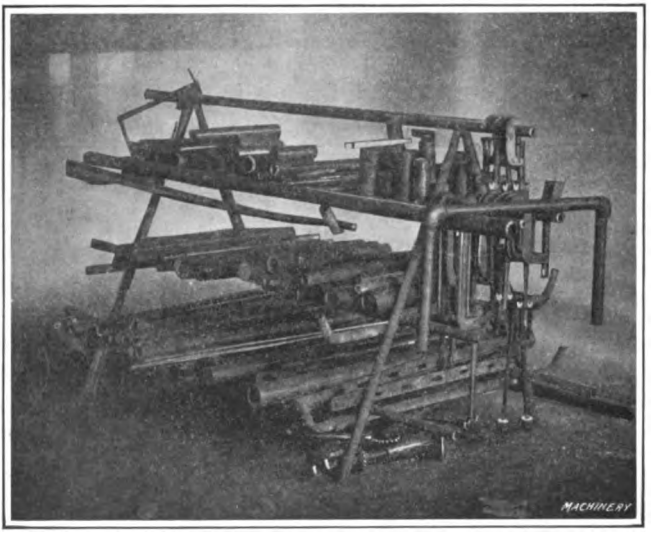


**Fig. 25. Rack for Mandrels, Blocking, and Other Tools**

**Rack for Bars and Mandrels.** — The general tendency in a shop of any kind is to allow bars, mandrels, or similar material to lie around in corners or under the bench, where they are difficult to reach and frequently damaged. A rack for such parts, shown in Fig. 25, is safer, and improves the appearance of the shop. This rack is about 5 feet long and 3 feet high, and is made out of old $\frac{3}{4}$-inch pipe welded together. On the right-hand end is shown a device which in its different forms is frequently of service in preventing the melting of babbitt bearings. It cannot be used in all cases, but, where there is much work of one kind to

be done, it pays to use it. This particular device consists of cold-drawn steel tubing about $\frac{1}{8}$ inch thick and of proper outside diameter to fit the bearings of the Ford automobile cylinder block. When it is necessary to do any welding on one of these cylinders, this piece is clamped into the bearings, just tight enough so that it will not turn readily, and filled with water. The ends shown hanging down stand up straight. Any change in the position of the cylinder in the fire can be taken care of by keeping the legs upright. It is necessary to watch the water carefully so that it does not evaporate.

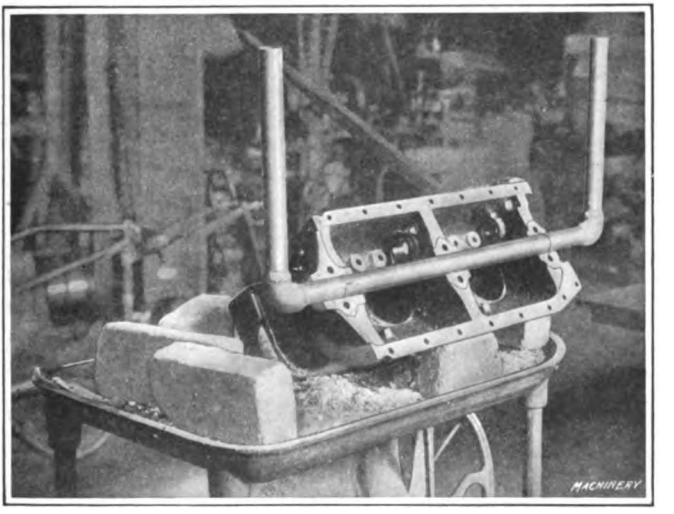


**Fig. 26. Pipe Mandrel used to prevent Melting of Babbitt Bearings**

**Cooling Device for Babbitt Bearings.** — Fig. 26 shows the use of this cooling apparatus. The illustration shows the device held in place by wires. This was found at the first trial to be unsatisfactory, as it did not hold the pipe in contact with the bearings closely enough, and at the present time bolts and $\frac{1}{4}$-inch pieces of steel are used to overcome the trouble.

**Miscellaneous Equipment.** — A substantial work-bench with one or two vises should be provided. If two vises are provided, one vise should have jaws 5 inches wide, for general use; the other may be a second-hand one, to be used for holding pieces

while welding, when they cannot be easily blocked up so that the welder can reach all parts of the weld. The good vise should never be used for welding, as the heat will in the course of time draw the temper of the jaws. The total number of vises and the size and number of benches required will depend upon the number of welders employed. For four men, one old vise and two good ones will be sufficient; the bench may have a length of about 25 feet, or three small benches may be used. Several pairs of "pick-up" tongs for handling bricks and other hot objects, and gas pliers in 10-inch and 13-inch sizes for use around the forges are necessary; their screw-driver ends should be ground off or bent over to make them safe when lifting with the end toward the face, as the sharp end has caused bad injuries. As soon as the jaws become slippery, the pliers should be thrown away.

*Refractory Graphite Mixture.* — In many cases, especially where the pieces are made of cast iron, and heavy, or where lugs or projections have to be built higher than the adjacent surfaces, time will be saved by building a dam of some refractory material of the proper shape and melting the metal into it. The best material for this in the case of cast iron or steel is a graphite mixture, such as is used in crucibles. This can be obtained in blocks of any size and shape, by ordering it specially; but rectangular blocks from $\frac{1}{2}$ inch thick and up, and round rods of various diameters, for use in keeping holes from filling up, are stock sizes, and can be obtained on short notice from crucible manufacturers. An assorted stock will be of great aid in quick work. In using this material, it will be found advisable to have it in position while preheating. It is more or less porous, and, when covered over during the welding, the heated air coming from the pores will cause pin holes, as it has no other way to escape than through the weld. Preheating the graphite expels some of the air and leaves less to cause trouble; but if a smooth, thoroughly sound weld is required, it will be necessary to turn the piece over, remove the graphite, and melt the metal until the blow-holes are eliminated.

*C-clamps and Hand Tools.* — An assortment of C-clamps, with from 3- to 10-inch opening, is needed for clamping work

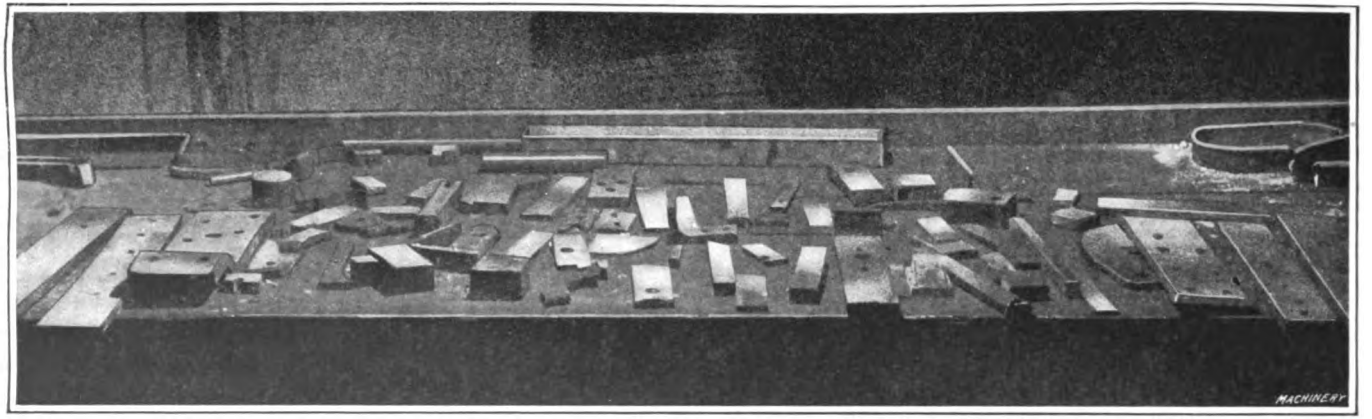

Fig. 27. Miscellaneous Clamps and Blocking required in Welding

together or to the table; also two bar clamps taking in about 30 or 36 inches, such as are used by carpenters; these are handy for long work. Of course, the regular metal-working hand tools will be needed, such as hammers, chisels, files, hack-saws, calipers, squares, straight-edges, surface gages, etc. A number of cold-rolled steel bars, about 30 inches long and of various diameters, are of great assistance in lining up automobile crankcases and other parts. They may be obtained as they are needed.

*Parallels and Liners.* — A collection of pieces of scrap of various sizes and thicknesses for liners, as shown in Fig. 27, is necessary for lining up. The thicknesses will range from a piece of tin to 2 inches. The thicker ones should be of cast iron, to avoid injury by heat. It is also of advantage to have some of the thicker pieces in pairs and planed to the same thickness. These pieces should not be exposed to great heat, to avoid warping them.

*Asbestos Paper.* — Asbestos building paper is used to protect the welder from the heat; to confine the heat to the piece being heated; to keep drafts off a casting that has been welded, which without such protection would tend to crack; and after it has been broken up so small as to be useless for these purposes, it is valuable for packing cylinders, etc., to allow them to cool uniformly. This material comes in rolls of about 100 pounds and in thicknesses varying from 6 to 12 pounds per 100 square feet. The 8-pound material is heavy enough for general use.

**Plaster-of-paris Patterns.** — Some knowledge of pattern-making is very helpful, especially where pieces of some size are missing. It is expensive to fill up such places with the torch. If a pattern can be made to fit, its use will make a cheaper and better-looking job, particularly if the surface is irregular. Even if the pieces are not missing, but are many in number and small, so that the total length of welds would exceed the length of the weld required if a single casting were used for the repair, it generally pays to make one. Plaster-of-paris is the most convenient material to use for patterns for this purpose. Wooden patterns are very expensive, and, unless they are simple and a number of castings are to be made, are out of the question. It requires some experience to handle plaster-of-paris successfully, and it is impossible to lay down rules for its use that will fit all cases. Therefore, the following suggestions will not always apply, and good judgment and ingenuity will have to be used:

1. Do not mix the plaster too dry, or it will set too soon.

2. Do not mix too much at once, but have several batches ready to mix one after another, if a large quantity is needed.

3. Prepare the piece by chipping or in other ways, so that the pattern will come out easily.

4. Make the shape of the pattern as simple as possible, by cutting out irregularities around the sides. The sum of two sides of a triangle is always greater than the third side, and cutting off angles, of course, means a saving in welding.

5. Bevel the edge of a cast-iron piece before pouring the plaster-of-paris, and bevel the edge of the pattern before taking it out; it comes out more easily and saves preparing the casting.

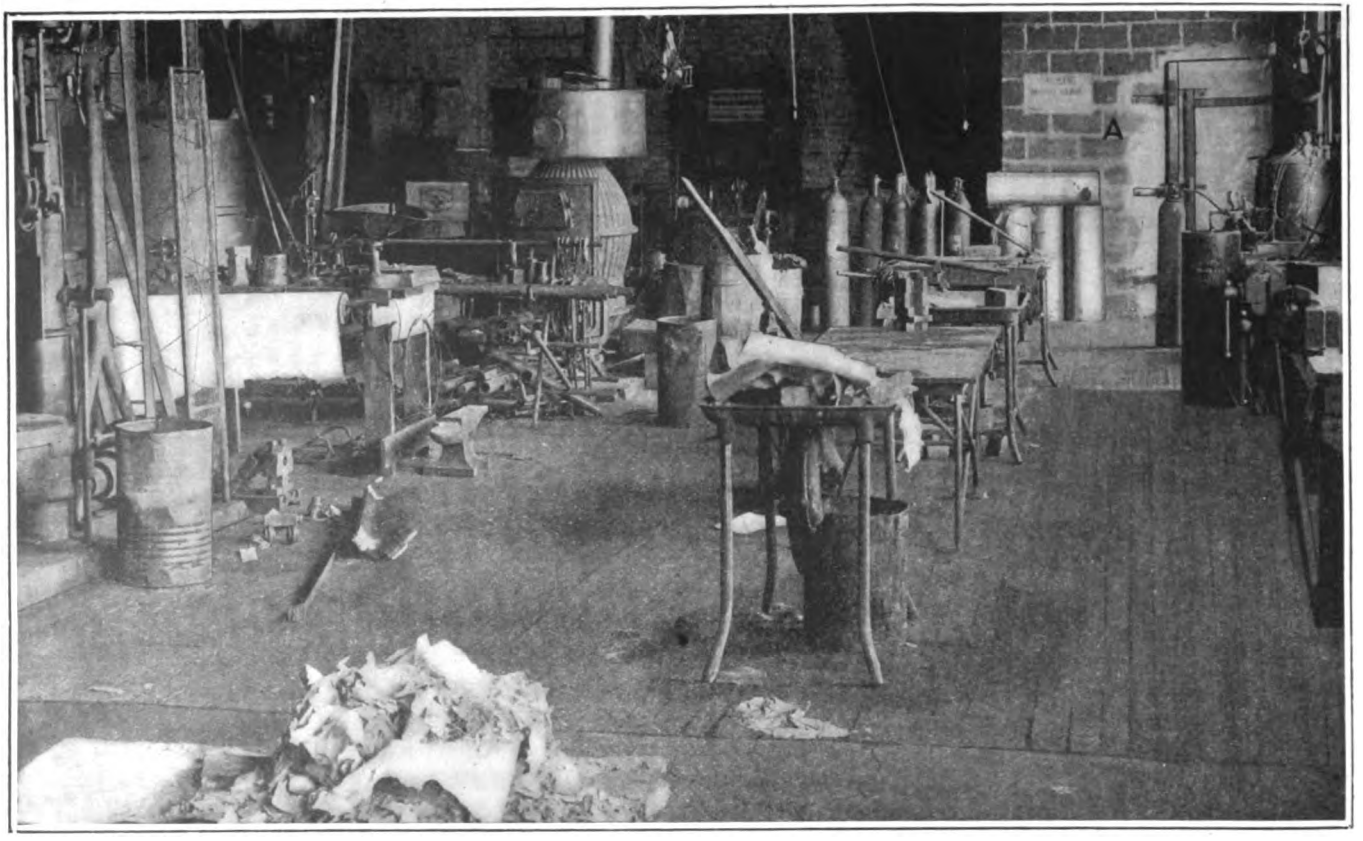

Fig. 28. View of Welding Shop

6. Do not bevel too much, but leave enough so that it can be fitted tightly in place. This helps in less contraction of the weld. The fit need not be perfect, but the better it is, the better the job will be.

7. In the case of aluminum, fit well, but do not bevel unless over $\frac{3}{8}$ inch thick, and then leave about $\frac{1}{4}$ inch bearing, as aluminum crushes easily when hot, and there should be bearing enough to force expansion without crushing, if possible.

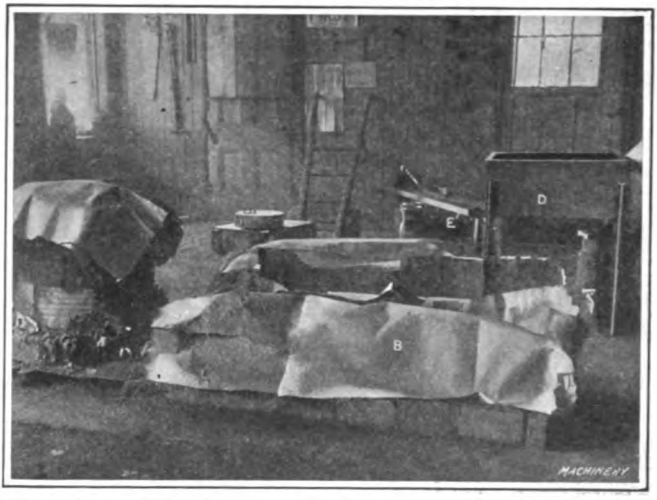


**Fig. 29. Preheating Floor for Building Fires**

8. Have the molder rap the pattern well; the shrinkage of cast iron in cooling is $\frac{1}{8}$ inch per foot, and of aluminum $\frac{7}{32}$ inch per foot. In the case of large patterns it will be necessary to add the needed amount to the proper edges and surfaces to allow for the shrinkage, and enough more to permit of any finishing that may be necessary.

**General Shop Arrangement.** — Fig. 28 shows the interior of a welding shop. The arrangement is not ideal, because there are windows only on one side of the shop, which leaves considerable floor space that cannot be utilized; but the arrangement of the forges and welding table should be noticed, particularly with reference to the work-bench. In arranging a welding shop, the welding table and forges should be located near a good light,

preferably daylight, so that the lining-up of work can be done quickly and accurately. Old carbide cans are used under the forges to catch the ashes from the charcoal fires. These cans are kept partly filled with water all the time. Before closing at night, the wooden floor around the forges is well soaked with water.

The acetylene generator room *A* is built in accordance with the underwriters' requirements and has a standard fire door. No light, except daylight, is permitted in the room, nor is there any opening except one window and the door into the shop. It would be preferable to have the door opening from the outside of the building into this room, but in this case it could not be so arranged. The work on the concrete floor shown in the foreground is reached by the use of long hose extending from the regulating valves on the wall.

Fig. 29 shows the concrete floor on which the heavy welding is done. In certain cases, as, for instance, when a large number of cylinders are to be repaired, and the forges are in use for other work, special fires, as shown at *B*, are built on it. Of course such fires are not built directly on the floor, but on sheet-iron or cast-iron plates which rest on bricks. There are four cylinders of various sizes in the fire *B*. At *D* is shown a homemade furnace lined with firebrick 1 inch thick on the bottom and sides, which is used for preheating. Its dimensions are 25 by 21 by 10 inches, and the top angle iron is 34 inches from the floor. A better size is 42 by 21 by 12 inches deep. A furnace of these dimensions would be large enough to handle the largest "six-in-block" cylinder made.

**Fire Risk.** — Chlorate of potash and carbide are both dangerous from a fire standpoint, and should be kept outside of the shop, preferably in a shed separated entirely from the building. Most, if not all, cities regulate the storage of these chemicals. If possible, a shop location should be selected away from a bad fire risk, such as a lumber yard, planing mill, cabinet shop, oil store, etc., as these automatically increase the insurance rate no matter how well the welding shop is protected. The installing of automatic sprinklers should receive careful consideration,

particularly with a low-roofed building, as the heat from heavy welding fires is great. Overhead wooden truss members and joists should have the accumulation of dust cleaned off at frequent intervals, as it is liable to catch fire from charcoal sparks. A coat of whitewash, using the acetylene generator residue, is a good thing to keep sparks from catching, as well as being of considerable assistance in lighting the shop. Charcoal fires should be kept covered with asbestos paper to hold sparks down. It should be remembered that even if the fire insurance were paid the day after the fire, there would be a great loss from not being able to do business and that, therefore, all precautions should be taken. Insurance should be considered as a protection against the mistakes of others, and not as a license to be careless. If every one would act as if no insurance could be collected for damage caused by his own carelessness, there would be fewer fires, and insurance rates would not be as high as they are.

**Eye Protection.** — Dark glasses should always be worn while welding, as the eyes are liable to be injured, particularly by the intense glare from the flux used in welding cast iron. For cast iron, very dark glasses, with a greenish tinge, are most suitable. For other metals, lighter colored glasses are better, as they permit a clearer vision of what is being done. In any case, glasses are dark enough, if immediately after welding it is possible to see clearly without being bothered with white spots in front of the eyes after taking off the glasses.

## CHAPTER II

### PREPARATION OF WORK FOR WELDING

It is generally essential that a weld be made through the whole section of a break. Sometimes this is not necessary, and in exceptional cases it may be impossible; for instance, in the case of a break through the eye of a cast-iron piece, where the diameter of the hole is small compared with its length, it is generally impossible to reach all of the crack with the torch from the inside of the hole, and there is danger of producing hard spots, which cannot be removed except with special grinding machinery that is not usually available. In such cases extra caution must be used to insure a satisfactory job.

**Beveling of Edges.** — For ordinary work, it is sufficient to bevel the edges of the broken parts so that when placed together the included angle will be 90 degrees (see Fig. 1), and so that just enough of the old break will be left to enable it to be correctly set up for welding. The reason for opening the break to a 90-degree angle is to permit the flame of the torch to reach the bottom of the V, so that the metal may be melted thoroughly and the natural bridging effect of the melted metal, with the resulting imperfect weld, may be avoided. It is not unusual for even an experienced welder to find such an imperfection in one of his welds, particularly if it is a "rush" job; and it is one of the difficulties a beginner must carefully avoid, particularly if the piece can be welded from one side only, as is frequently the case. In such cases the crack must be entirely burned through with the torch, even if drops of metal remain hanging under the weld. It is especially important that the 90-degree angle be maintained in preparing steel. This metal sets so rapidly that the bottom of the weld will be full of cold shuts, or a great amount of time will be lost and gases wasted in burning away metal to secure a good weld, unless the beginning of

the weld is made easy to reach. It is also advisable to have plenty of room for the flame to spread, in order to avoid overheating the head and the tip.

A very good way of preparing parts where there is not sufficient room for a 90-degree angle, and also for heavy welds, by which a considerable saving of gases and time may be accomplished, is to drill out the bottom of the crack with a $\frac{5}{8}$-inch drill and bevel the sides to less than 90 degrees. This applies to both steel and cast iron, and is especially useful when the break is in a corner, where it is evident that a 90-degree angle cannot be obtained. This method also frequently reduces the time of preparing the work, as with cast iron the remainder of the V can be easily removed with a sledge and handle chisel.

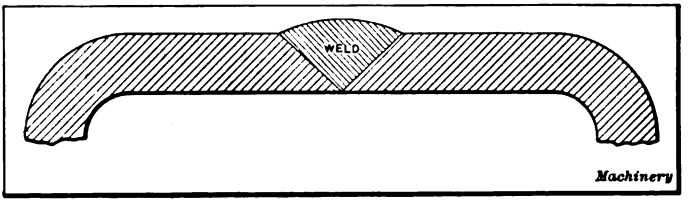


**Fig. 1. Method of Welding Thick Materials**

Instead of beveling only from one side, as in Fig. 1, it is preferable to bevel the work from both sides, when possible, resulting in a double V, as shown in Fig. 2. It will be evident that this needs only half the welding that a single V does, besides which it tends to produce a better weld. A crack remaining in the center of a piece is not nearly as dangerous as if it were on the outside, and the shallower the V, the more readily is a good weld made. Any method of making the V is allowable, the object being to open up the V well, and to permit of making the best and easiest weld. For small pieces of any metal, the use of an emery wheel is probably the best method. Cold chisels and sledges or hammers are excellent for cast iron, where the piece will stand their use. In some cases a hacksaw is most useful. Drilling along the crack and chipping out the bridges roughly is a good method where the piece is cracked and not broken. The drill should be ground to an included angle of the lips of

about 120 degrees, and the point of the drill should just go through the metal. If it goes too far, there will be trouble on account of the bottom of the hole burning through too quickly, especially if a heavy tip must be used. The diameter of the drill should be about equal to the thickness of the piece to be welded.

**Welding Pipe Fittings.** — There is one method which is of much assistance in such cases, for example, as that of a large pipe or pipe fitting flange broken off at the root, where the body of the casting is not very thick, say, $\frac{3}{4}$ inch. A fitting, such as an elbow, must be kept in a fire to avoid cracking and is awkward to turn while red hot, as well as "hard" on the welder. The part being welded would ordinarily be above the fire by an amount equal to about the diameter of the flange, which would allow it to cool rapidly, making welding difficult and probably resulting in a cracked casting when cooled. If, however, the inside of the crack be chipped out to the regular V halfway through, and the outside edges left nearly parallel and about $\frac{1}{8}$ inch apart, leaving a few narrow parts of the old crack to line it up by, the elbow can be set with the flange downward in the fire and allowed to remain there until the outside is entirely welded. This is easily done by playing the flame between the parallel sides of the crack, which, as they confine the heat closely, soon become melted, and run together at the bottom, with careful handling of the torch; after this, sufficient metal is added to complete the outside of the weld. It is then an easy matter to weld the inside, as the part worked on can be in the fire all the time.

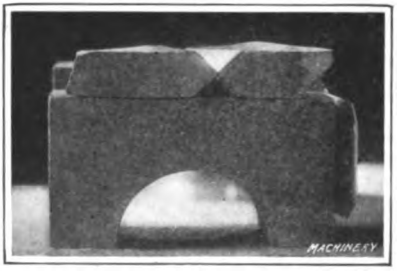


**Fig. 2. Work Beveled from Both Sides**

**Welding without Beveling.** — It is sometimes best not to bevel the edges of the pieces. This is true of thin pieces, where it is unnecessary. In the case of cast iron and steel, pieces $\frac{1}{8}$ inch thick or less can be welded without making the V. In aluminum nothing less than $\frac{1}{2}$ inch thick, and in brass and

bronze nothing less than $\frac{1}{4}$ inch thick should be beveled. These rules are only approximate, and experience will determine what should be done. At the beginning, it may be best to bevel everything with the exception of very thin pieces, except in aluminum. Sometimes it is best to burn out the crack without beveling it. This is true of an irregular piece, not very heavy in section, on which there are no finished surfaces that can be used for lining up, and which has to be lined up true by the crack. Burning out is expensive and should not be resorted to unless necessary. The metal is melted with the torch, and pulled out with the welding stick until the V is made, when the welding proceeds as usual.

It requires considerable ingenuity sometimes to prepare a piece, especially a heavy one, with an irregular break, so that a minimum of handling will result, as it is neither desirable nor comfortable to handle a heavy red-hot piece. After it is once set up, it is sometimes dangerous to turn a heavy piece over, as the weld may break, or a sudden draft may crack it outside of the weld. The author has seen many pieces where the first consideration in preparing has been ease of handling while hot, and the cheapness of preparing has been a minor matter.

**Handling Heavy Hot Pieces.** — It is well to consider the handling of heavy hot pieces; they have frequently, even with the best preparation, to be turned over or moved during the welding. One must not be at all uncertain of what to do at such times; and it has been found very helpful in case of doubt to put the cold piece through the motions that are thought to be advisable when welding, using chains, hoists, bars, rollers, etc., just as if the piece were hot. The temptation to use the hands on the piece in this test must be carefully avoided. This trial shows what changes, if any, should be made in the plans, and also has the advantage that all tools used may be laid together till needed, and great loss of time and temper avoided by not having to look for them while under stress of work. It would appear, therefore, that before starting a job careful attention must be paid to planning, as the preparation has a very important bearing on the quality, speed, ease, and cost of the work.

**General Remarks on Preparation for Welding.** — After the piece is beveled, it is necessary to set it up so that it can be readily welded; the method of preparation will have an important bearing on this, sometimes deciding the question. Other things being equal, the piece should be set with the weld on top, so that the melted metal will not run away. It is easy to weld steel on the side or even on the bottom of a piece, and cast iron, brass, and bronze may also be so handled by an expert welder; but it is more difficult to produce as good a weld, and some metal is lost, making it a slower and more expensive process. Aluminum can also be so welded, being nearly as easy to handle as steel, but it is seldom necessary to resort to the practice.

**Alignment.** — Next in importance to a sound weld, and even sometimes more necessary, is the need of so welding the piece that it has such finished surfaces as required in line. Of course it is not possible in all cases, and is difficult in any case, to produce a perfect condition. In some cases allowance must be made for machining. No rules can be laid down; but sometimes metal can be added so that the part can be machined to the original size; sometimes machining may be done without adding metal. Sometimes the metal may be heated and sprung or peened into place, or this may be done cold. Steel may be so treated, either hot or cold, depending upon the nature of the piece; aluminum, brass, bronze, and malleable castings must be peened or bent cold; cast iron cannot be so treated, but may sometimes be bent or straightened by clamping one end on the table, heating with the torch to nearly the melting point, and pulling down on the other end with another clamp very slowly.

**Warping or Cracking.** — Warping or cracking is caused by the expansion and contraction due to the heat of welding It is not possible to avoid these conditions, and they, therefore, must be controlled by making allowance for them. The principle of control is best illustrated by a simple test, as follows: prepare two pieces of cast iron as shown in Fig. 3 and bolt them tightly to some heavy piece of metal; the sides of the holes should bear against the bolts and the bottom edges of the V just touch. The heavy piece to which the smaller pieces are bolted is kept

from being expanded by the heat from the torch, by being put in water, or by some similar method. Then make the weld, using no more metal than enough to fill the V and doing the work as quickly as possible, but being sure to burn through the bottom so that the weld will be sound. On cooling off, the piece will invariably break somewhere, and there will be a gap between the pieces which, in the case shown, amounted to 0.011 inch.

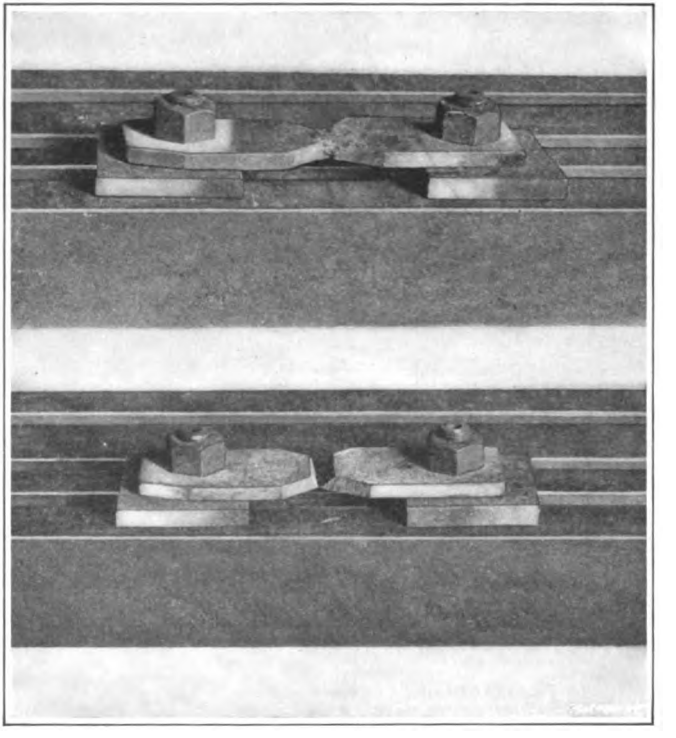

**Fig. 3. Illustration of Contraction Stresses**

If the piece the work is bolted to is not rigid enough, or the fit of the bolts against the holes is not tight, or if there is a trifle of spring in some of the parts, a light tap on the piece may be necessary to cause it to break; but the gap will always be there after breakage. If another test-piece be made, and the ends left free, there will be no difficulty in making a satisfactory weld. Again, if the bottom edges of the V are butted together, the ends

of the piece will rise, which is only another manifestation of shrinkage, as the metal on top is hotter than at the bottom, and the bottom edges act as a fulcrum. The remedy is to leave the pieces slightly apart, or to clamp or weight them down.

These things occur in every welding job, whether it appears so or not. Holding the ends rigid compels the expansion from the heat to go to the center, and, when the piece cools off, there is sufficient contraction to break it. It is very easy to ascertain what happens in a simple case like the one given, but the successful application of the principle to complicated and unusual cases is a different matter. As a matter of fact, making a sound weld is a comparatively easy thing to learn, and many learn it; but the control of expansion and contraction is much more difficult to understand, as it requires a development of the imaginative faculty that is rarely met with, and there are few who master it.

**Setting-up Work for Welding.** — In setting-up a piece for welding, it should be done, if possible, on a planed surface plate or table, using the finished surfaces of the piece, if any, to go by. Of course, the pieces should not be laid directly on the table, on account of the chilling action of the cold surface, but parallel strips, or other pieces of like nature, should be used to keep the parts above the table, and they should be located, if possible, some distance from the weld. If there are no finished surfaces, or if they cannot be used, set up the piece before making the V, using the crack to determine the necessary amount of blocking to hold it in line, and clamping it so that it will not move. Then remove the pieces without disturbing the blocking, V them, replace on the blocking, and reclamp. It is well in all cases of complete breakage to separate the parts of the final set-up by just enough to compensate for the shrinkage of the weld. This is absolutely necessary if the original dimensions have to be maintained. The amount of separation varies with the piece and material, but generally $\frac{1}{32}$ inch in cast iron and $\frac{1}{8}$ inch in aluminum will be sufficient. The correct amount is determined by experience. Sometimes the allowance will be incorrect, and the piece will have to be cut and rewelded, changing the allowance.

In case great accuracy is needed, tram-marks must be made on the pieces with a very fine pointed tram; center-punch marks are of little value, except to keep the tram-marks from being lost, and the tram-marks must be used.

Frequently it is necessary to set up pieces in the fire, either because they are too heavy to weld otherwise, or because of expansion or contraction causing them to break, if welded cold. In such cases, block them up as if on the table. Care should be taken that the heat does not affect the blocking or pieces so as to destroy the alignment, which should be again tested before welding; be careful to arrange the blocking to allow this. Sometimes such pieces may be clamped to a heavy block, preferably of cast iron, which does not bend as readily under heat as does steel. The clamps and block should be protected from the fire, or exposed to air to keep them cool, if possible. It is also possible, at times, to take red-hot pieces from the fire and clamp them on the table, or on previously prepared blocking, as the torch will keep the parts hot enough while welding. With heavy pieces in large fires on the floor, it is necessary to be exceedingly careful that the alignment does not change during preheating. The blocking must be of such material (preferably cast iron) and so arranged, that the danger of moving will be reduced to a minimum. The blocking must be on a foundation independent of the fire support, if there is any danger of the latter moving on account of the heat. In any case, allowance must be made for the contraction of the weld, by holding the crack open in some way.

**Preheating.** — The general principles involved in preheating may be briefly stated as follows: Parts to be welded autogenously are often preheated by the use of a blow-torch, gas furnace, charcoal fire, etc. This preheating is done either to economize in gas consumption or to expand the metal before welding, in order to compensate for contraction in cooling. Usually it is advisable to preheat comparatively heavy, thick metals (especially if cast) before welding. This equalizes the internal strains, and very materially reduces the cost. In many instances it is much better to produce expansion before welding

than to attempt to care for the contraction afterward. When a part has been preheated, it is well to place sheets of asbestos over it to protect the operator and prevent heat radiation, the surface to be welded being exposed. Where a piece of metal has been severed completely, or a projection has been broken off, preheating will not generally be necessary.

**Charcoal for Preheating.** — Many pieces must be kept hot all over while being welded, and this cannot be done with the torch. Such parts as water-jacketed cylinders, cast-iron heating boiler sections, aluminum and cast-iron crankcases and transmission cases for automobiles, and other large castings, come under this head. Good hardwood charcoal is then the best all-around fuel. It burns without smoke, does not injure finished surfaces as does coal, gives off no offensive odors, burns slowly and evenly, does not need a fan blast to keep it going, will heat any piece red-hot, and is easily controlled. Many pieces have to be cooled off in the fire so that they will not contract too fast or unevenly. Charcoal is also the best fuel for this purpose, as the heat from it dies out slowly.

The best hardwood charcoal is necessary. That made from soft wood breaks up easily, has little heat, and clogs up the fire so that it does not burn well. It is advisable to remove the dust and small pieces, by screening through a $\frac{1}{2}$-inch mesh sieve. For handling charcoal from the storage bin to the fire, old carbide cans with the top cut out are very convenient and save many steps. It is well to store as little charcoal as possible, as it is easily ignited by a chance spark; and, as it gives no warning by smoke, it is liable, if ignited, to gain considerable headway before being observed.

**Other Means for Preheating.** — Gas furnaces are very convenient for preheating to reduce the torch gas expense, but for anything else they are of little value. Kerosene torches are frequently of value for heavy work of certain kinds, especially where no contraction strains exist. Gasoline torches cannot be recommended in a welding shop. In some cases ordinary Bunsen burners or modifications similar to those used in gas stoves may be used, particularly on light work. They are of

special value where many pieces of one kind have to be welded, because the burner can be made to suit the job. A very satisfactory method of preheating shafts and other solid pieces is by the use of a gas torch, using illuminating or natural gas and compressed air under about one-pound pressure. These torches may be held in clamps, and mounted on a flat firebrick-covered table, which may be surrounded with firebrick, to keep in the heat. It is necessary to have a blower to obtain the air pressure, and its operation is somewhat costly, unless there is plenty of work of this kind, which is not often the case in a repair shop.

**Object of Preheating.** — There are two objects for which preheating is used. The first, merely to heat the piece to save time and gas and make a better weld; and the other, to take care of the natural contraction of a welded piece. In the first case, which applies to plain heavy pieces, it is only necessary to put them in the fire, heat them as rapidly as possible, weld them, and allow them to cool off slowly. The second case is very different. Such pieces as gas engine cylinders (which have two walls joined together to form a water space), flywheels with heavy rims and light spokes, stamping press and punch-press frames with two rigid uprights, automobile crankcases of aluminum or cast iron, or any other pieces where the shrinkage of the weld would produce a strain, should be preheated in part or as a whole, so that the strains during the cooling may be equalized or eliminated. It is impossible to give any general directions, but specific cases are treated of later.

The only guide at the present time as to the amount to which a piece should be preheated is experience. It may be said, however, that as far as eliminating strains or securing a sound weld is concerned, taking nothing else into consideration, the hotter the piece is heated the better. Care should be taken, however, not to heat a piece so that it will distort. It is easily possible to heat a cast-iron piece so hot that if not properly supported it will sag at the unsupported place, and care must be taken to avoid this. This property of cast iron is, however, of value at times in straightening pieces that have been warped by welding, it being possible in many cases to clamp a piece at one end

rigidly on a true surface and pull the other end down slowly with another clamp, while keeping the weld quite close to the melting point with the torch.

The preheating should ordinarily be done rather slowly so as not to introduce sudden temperature changes and stresses. Slow heating is especially to be advised when there is a combination of thin and heavy parts. Similar remarks apply to the cooling, which should be slow to be safe; the cooling may be retarded by the use of asbestos sheeting or by packing the object in heated ashes or heated slaked lime.

**Temporary Furnace for Preheating.** — When it is possible to preheat the entire casting, this seems to be the best way of taking

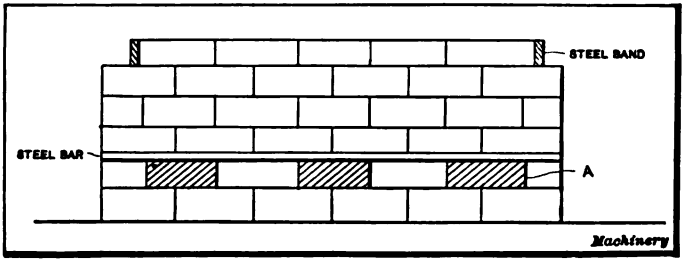


**Fig. 4. Arrangement of Temporary Brick Furnace**

care of expansion and contraction. Castings, the size of which makes necessary special arrangements, may be placed on a bed of firebrick arranged with spaces between them. A temporary wall or furnace is then built around the whole, firebrick being used for this also. These are arranged without the use of mortar, with very narrow openings between them, one method of constructing such a wall being shown in Fig. 4. Flat steel bars may be employed just above the separated course of bricks *A*. The top course may be held in place by a steel band. The object of the open spaces is to provide draft. A small amount of lighted charcoal is then placed around and under the casting, more being added, from time to time, until the required heat is reached. A sheet of asbestos is used as a cover. This cover should contain a number of holes, so as to provide an exit for the gases.

**Hood used for Preheating Operations.** — Another method is to make a hood of a material that is a poor conductor of heat. Such a hood is shown in vertical section in Fig. 5. The walls consist of two sheets of wire netting with an intervening space filled with asbestos. A hole, the wall of which is made of sheet iron, is provided at the top. Another aperture also lined with sheet iron is provided on one side of the vertical cylindrical wall.

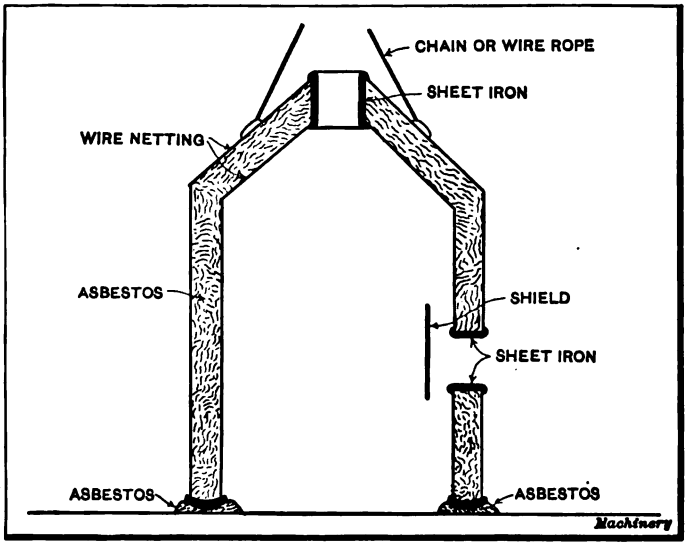


**Fig. 5. Hood used for the Preheating Operation**

The bottom of the hood is furnished with an annular base ring of sheet iron, the netting and sheet iron being joined by welding. Provision should be made for lifting and lowering the hood, so that it can be let down over the casting which is to be preheated. To make a tight joint with the floor, some loose asbestos may be used as a foundation for the hood. A kerosene or other torch may now be inserted through the aperture in the side. Some kind of shield may be used just inside of the side opening to divide the flame, so that, as far as possible, the casting will be encircled by it. Sometimes it is advisable to use auxiliary fires on shelves above the main fire at the bottom. This is especially to be recommended for tall castings, so that there will be no severe

concentration of heat at one point. As already mentioned, the heating should be done slowly, the fires being started in a moderate way and gradually increasing in intensity. During the welding, the hood must be raised, and when the welding is completed the hood may again be lowered into position in order to retard the cooling. The oil torch should be brought into service again for a short period. It may then be shut off and the openings of the hood covered. In this way slow and even cooling is assured. Devices of this kind are useful only for special purposes, and are, therefore, limited in application, although very valuable under proper conditions.

In general, after a welding operation, the casting should be reheated as soon as the welding is completed, and then covered with asbestos wool or scrap asbestos. The casting may also be buried in any of the materials ordinarily used for retarding the cooling of steel which is to be annealed, or may be cooled in the bed of charcoal in which it has been heated.

**Preheating Temperatures.** — The temperature to which any piece should be preheated depends upon the metal of which it is made, its shape, size, and the purpose of the preheating. As illustrations of the differences in preheating temperatures, consider, on the one hand, a heavy solid piece of cast iron the shape of which will not produce any shrinkage strains when cooling, and, on the other hand, a light complicated casting, such as an automobile cylinder. In the former case, it is evident that the purpose of the preheating is largely to save gas and labor, and that the preheating can be carried to as high a temperature as a good red heat, because there will be no danger from distortion or cracking. In the latter instance the conditions are entirely different. The preheating must not be carried to so high a degree as to warp the cylinder, and still it must be carried high enough to permit of contraction without cracking when cooling; also, in this case, the amount of gas saved by preheating is unimportant. In the former case the temperature may be as high as 1500 degrees F., while in the latter case it should not exceed about 800 degrees F., and, in some similar cases, where the shape of the cylinder is quite simple,

a lower temperature is sufficient. The temperatures may be taken with a thermo-couple. The variation of temperature in the different parts of the casting is considerable, in some instances there being over 200 degrees F. difference. As already explained, in preheating a cylinder a certain procedure should be followed, the latter part of which is to turn the defective part down, so that it may be warmed up to a somewhat greater temperature than the rest of the casting. When turning such a casting back, so as to reach the part to be welded, there is a drop in temperature of, in some cases, over 100 degrees F. in a few seconds. This, of course, takes place before the welding can be started. So many inaccurate statements have been made

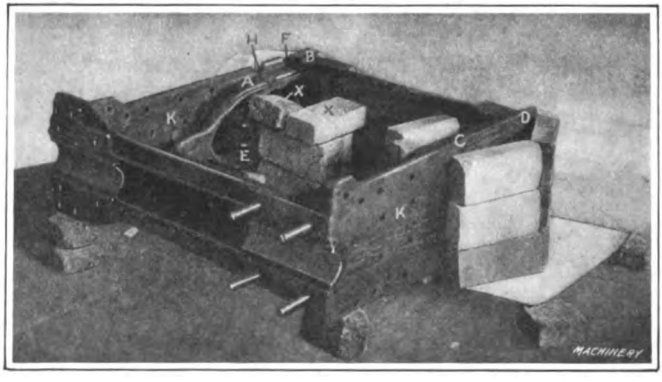


**Fig. 6. Example of Preheating**

as to the proper heating temperatures that the author believes that more careful tests are necessary in order to determine what these temperatures should be for different types of castings.

It should be remembered, however, that the conditions mentioned control the situation very largely, and that, because one type of casting can be safely preheated to 800 degrees F., another casting of a different type or shape may possibly, if heated to the same temperature, cause trouble. Therefore, any figures given, even when they are accurately determined, should be followed with caution and used with good judgment.

The only other metal which, as a rule, gives trouble during preheating and cooling, is aluminum, because of the complicated

shapes in which it is usually cast, such as crankcases, transmission cases, etc., and from the fact that a slight distortion of such castings makes it difficult to use them after welding. Aluminum alloys melt at a temperature of about 1200 degrees F., but long before this temperature they will bend, if subjected to any strain, and frequently from their own weight, which action is, of course, the same as in the case of iron and steel, although

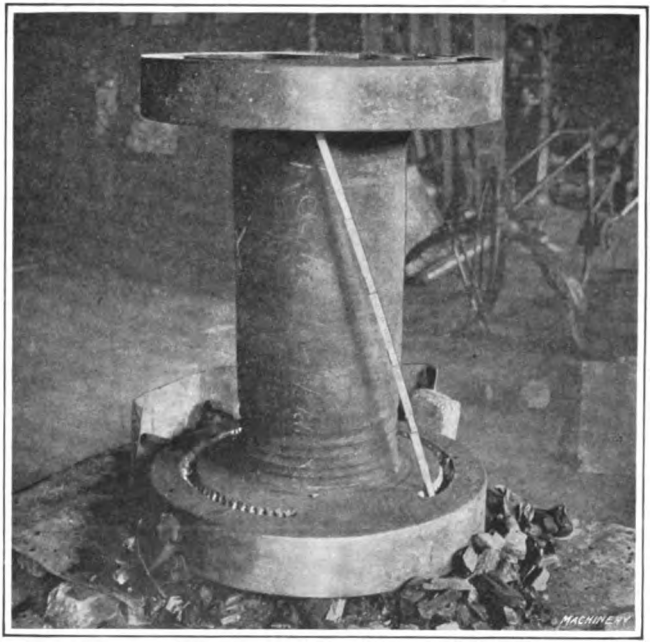

**Fig. 7. Hoisting Engine Drum prepared for Welding**

cast iron is not influenced so much as the wrought metal. It is, therefore, unsafe to preheat to anything like the temperature which is safe in the case of cast iron; about 500 degrees F. is the safe limit, and, for all ordinary cases, this is ample. With aluminum-zinc alloys, where trouble might occur from cracking just after welding, the piece may be heated to about 600 degrees F., but care must be taken to avoid distortion of the casting by its own weight. It should also be remembered that, in all cases of preheated castings, the metal becomes, during the course

of the welding, appreciably hotter than the preheating temperature, and a beginner will frequently not notice this, particularly in the case of aluminum, until it is too late.

**Examples of Preheating.** — In Fig. 6 is shown an instance of the necessity of proper preheating to insure sufficient expansion so that there will be no strain in the piece after welding. The two sides $K$ are identical in construction and the section below the piece broken out is identical with it. The casting is about $3\frac{1}{2}$ feet square, and the thickness of the welds, except at the flange, is about $1\frac{1}{4}$ inch. In order to check the expansion, tram-marks were made at $A$, $B$, $C$, and $D$, $AB$ being equal to $CD$. Inasmuch as the casting was very rigid, it was necessary to take special precautions to avoid strains in the welded piece. The method followed was to heat the side $CD$ both top and bottom to a sufficient temperature to give an equal expansion to that of the side $AB$, which was heated only at the bottom, in order to keep the top as cool as possible, forcing the expansion to take place everywhere except at the break, the torch being sufficient to counteract the heat at the part below the break. The fires were started slowly, charcoal being used. The fire on the side $CD$ is longer than the one at $AB$, the latter being very little longer than the piece broken out, but care was taken to tram both sides just before welding to be sure that the expansion was the same.

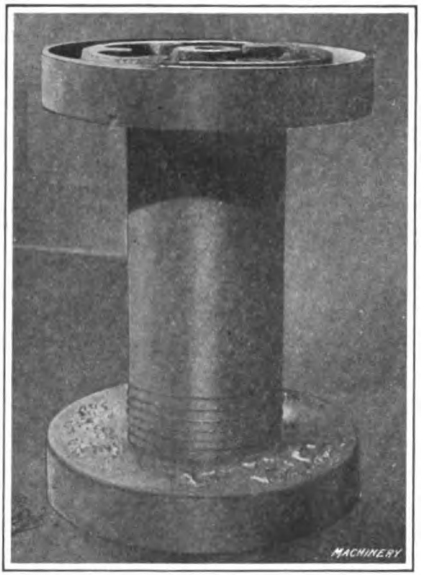


**Fig. 8. Same Drum as in Fig. 7, Welding Completed**

During the firing, side $CD$ was kept covered with asbestos paper, while the piece broken out and the casting in the vicinity

were not so covered. Care was taken, however, to prevent sparks from rising from the fire by covering the space between the bricks and *AB*. The illustration shows the bricks *X* laid on their side to permit a good view of the breaks, but they were later placed on edge in order to confine the heat. The fire, however, was not allowed to reach the break, but was kept about 3 inches above the bottom section. A large tip was used to make the welds, as the casting was comparatively cold. Weld *F* was made first, allowed to cool to the temperature of the casting, the tram-marks checked again, and then weld *H* made. Both welds were burnt entirely through from the top, and each one was finished underneath after it was made, taking down enough of the outside bricks to reach it, and covering over the fire to hold the heat in the bottom section. After welding, this cover was removed, the bricks replaced, and the casting allowed to cool down in the fire. It was found that before welding at *H*, the crack was open about $\frac{1}{8}\frac{1}{2}$ inch, which was sufficient under the conditions to take care of the contraction. It is necessary in this and similar cases to make the weld as quickly as possible, so that the heat conditions at all points will remain as nearly constant as possible.

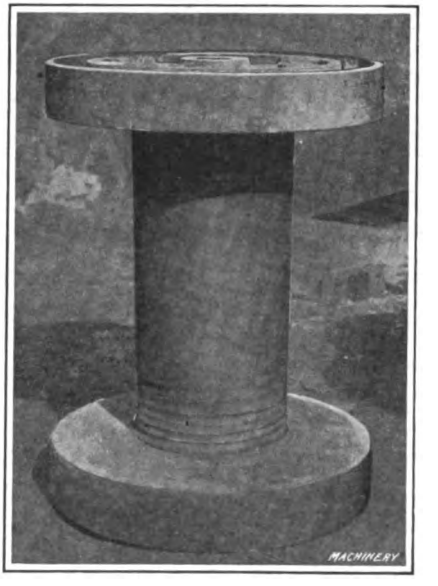


**Fig. 9. Drum shown in Fig. 7 finished**

**Preheating a Rope Drum.** — Fig. 7 shows the method of preparing, blocking up, and preheating the rope drum from a hoisting engine. Both ends were cracked in the same way, although the upper one in the illustration was not cracked so badly. It was impossible to prepare the drum from the other

side, which would have been desirable on account of the greater ease of doing the work, as it could have been done under a drill press. The crack extended through at the root of the friction block cavity, making it impossible to prepare by any other method except that used. An electric drill was used and the necessary material chipped away as shown, the same procedure being followed on both ends to produce the V's. As the casting was quite heavy, it was necessary to block it up inside of the crack, because if it had been blocked up under the outside, it would probably have been distorted when it became red hot. Fig. 7 also shows the pieces of sheet iron practically surrounding the casting, and the charcoal in place ready to ignite. Of course, pieces of sheet iron entirely surrounded the flange during the preheating, welding, and cooling off. Care was taken to melt through the bottom of the crack to insure a sound weld. Fig. 8 shows the piece after welding. There was no necessity for any finishing except just sufficient grinding with a flexible shaft emery wheel to remove the principal roughness, so that the rope would not chafe. The finished appearance is shown in Fig. 9.

## CHAPTER III

### MATERIALS AND FLUXES USED FOR WELDING

In nearly every case of oxy-acetylene welding it is necessary to use additional material to fill up the V left by the preparation of the piece. The material to use for this purpose depends partly upon the metal in the piece and partly on the result desired; in almost all cases this additional metal is furnished in the form of wire or rods from $\frac{1}{16}$ to $\frac{3}{8}$ inch in diameter. Special cases may require larger or smaller sizes, but it has been found that the range given is ample to cover the ordinary run of repair work.

**Welding-rod for Cast Iron.** — For welding cast iron, the material used is cast-iron rods from $\frac{3}{16}$ to $\frac{3}{8}$ inch in diameter, the small rods being used for small work and small tips, while the heavier rods are for the larger work and heavy tips. When the pieces of the welding-rod become too short to hold comfortably, they may be welded together, and so used up. The cast iron in these rods should be of first-class quality, high in silicon and low in manganese and sulphur, so that it may be easily melted, reducing the gas consumption and, consequently, the expense, and producing a soft weld. These rods are at present a specialty; it is a serious mistake to use cheap welding-rods of improper composition, as the gas consumption is much higher, and the work much slower and of poor quality, resulting in increased cost and unsatisfactory results.

When oxy-acetylene welding first became a commercial process, great difficulty was experienced in welding cast iron, on account of the hardness of the welds, which prevented their being machined in any way, except by grinding. This was due to the use of ordinary cast iron for welding rods. Such cast iron has comparatively little silicon and considerable manganese and sulphur in it. Silicon promotes the formation of graphite in iron, which makes it soft, while manganese and sulphur have

just the opposite effect; thus it will be seen that the use of ordinary cast iron tends to produce white iron or chilled iron containing no graphitic carbon, and which is intensely hard. The increase of silicon and the decrease of manganese in welding-rods overcomes these objections and makes possible the production of a soft weld. The manufacturing of such welding sticks cannot be carried out in an ordinary foundry, as the iron is not suitable. Therefore, it must be left to those who make a specialty of this work. There are several foundries in the United States that do nothing else, and the material can be obtained from them, or from the manufacturers of welding apparatus.

**Welding-wire for Steel.** — In welding steel, nothing but the best and most suitable wire should be used. Wire purchased at an ordinary hardware store is of no value, as it is of improper composition, being frequently high in sulphur and phosphorus, and, as a rule, also too high in carbon; hence, it will not give good results. It is generally claimed that Swedish (often called Norway) iron wire is the best for this purpose and that the imported wire is better than the domestic. This is true for ordinary steel, although it does not make a homogeneous weld. A highly polished section through a weld made with Swedish iron wire shows a very marked difference between the original and added materials. Etching such a piece for microscopic examinations shows the difference still more clearly, the etching action being much slower on the added material. It is, however, somewhat of a question whether material with a small percentage of carbon, say, 0.1 per cent, or, perhaps, as low as 0.05 per cent, would not give just as good results, provided the impurities, such as sulphur and phosphorus, were kept to as low a point as is the case in Swedish iron. There are other matters in connection with this subject that have never been investigated, as far as the author knows, and inasmuch as their investigation requires great accuracy, and considerable time and expense, the lack of information is not to be wondered at. It is a fact, however, that the use of Swedish iron or any pure iron wire gives good results, and, until the matter is more carefully investigated, one is safe in using that material.

There are advertised a number of other materials, such as nickel steel, vanadium steel, etc., with which the author has had but little experience. On theoretical grounds, however, the use of these materials is questionable. Vanadium is never added to steel in any appreciable amount. Whether such steel would retain its properties after being heated to the welding temperature is still another question, and if a weld can be produced by the use of Swedish iron, which is strong and ductile enough, the use of alloy steels appears to be unnecessary. The use of alloy steels for welding has never been carefully investigated, and, as in other matters of this kind, innovations should be considered with caution.

**Alloy Steel Welds.** — It should be remembered that any weld is a casting, no matter what the metal may be, and that it is impossible, in most cases, to produce as satisfactory a condition in the weld as in the original metal, even with the best welding material and fluxes, unless the weld can be given the same rolling or forging treatment as that to which the original metal was subjected. In the case of alloy steels, which are largely used in automobiles, proper heat-treatment must be given in addition to forging of the steel. These results are not often possible to obtain, because the piece cannot generally be forged; nor does it contain the necessary elements for successful heat-treatment, since the joint is not a homogeneous weld. In addition, no welding shop has facilities for conducting such heat-treatments. Therefore, in such cases, a welded piece will not give satisfactory results. This is not the fault of the welder, of the material, or of the flux, but is an inherent limitation of the process. It is, therefore, advisable to avoid welding such steel pieces, except in case of emergency or for temporary purposes only.

**Welding-wire for Spring Steel.** — It is sometimes advisable or necessary to weld broken leaves in automobile springs, and while it appears a doubtful performance, as far as strength is concerned, the author has never known one welded in his shops to break. The proper material to use for this is old bed springs, which can usually be found around an ordinary scrap yard. Ordinary welding-wire is not satisfactory. Care must be taken

in using this material not to burn it. A fairly large tip should be employed and the work done rapidly.

**Welding Material for Steel Castings.** — The welding of steel castings is generally possible and gives good results. There are some kinds, however, that are difficult to weld, and others can only be welded with cast iron. Evidently, if strength is a consideration, cast iron must not be used. Usually ordinary welding-wire is suitable, but it is well to keep the pieces that are cut out during the preparation, so that, in case it is found difficult to weld with ordinary steel, the pieces themselves may be used as a filler, at least as far as they will go. Sometimes it is possible to cut off surplus metal from other parts of the casting and use it.

**Welding Material for Tool Steel.** — The welding of tool steel is generally unsatisfactory, particularly where the material is to be used for heavy cutting. It is not possible to avoid entirely the burning of the metal. Borax or other suitable flux should be used as a coating for the steel, to help keep the air from it. The use of spring steel wire for filling, and of a rather large tip, with the quickest possible speed for doing the work, will give as good results as can be obtained. It is a material that is very seldom handled in repair shops.

**Welding-rods for Copper and Copper Alloys.** — For welding copper, copper wire or rod having a small percentage of phosphorus is advisable. The phosphorus eliminates the oxygen which would otherwise be absorbed by the copper, and which would make the weld porous. The amount of phosphorus in the welding-rod should be such that none of it is left in the weld, or a brittle constituent is likely to be present.

The alloys of copper include the various brasses and bronzes, which are exceedingly numerous and of a great variety of compositions. A brass is an alloy of copper and zinc. A bronze is an alloy of copper and tin. These alloys may have added to them lead, antimony, iron, manganese, nickel, etc., in smaller percentages than the main constituents. Inasmuch as it is impracticable in ordinary repair work to determine the percentage of the elements in copper alloys, it is manifestly impos-

sible to make a truly homogeneous weld, i.e. one containing the same elements as the piece to be welded. Of course, where the process is used in manufacturing and the composition of the alloy is known, some experimenting will enable one to determine the most suitable mixture to use for welding-rods; but in repair work it is necessary to find some one or two alloys which will apply to all of the metals that are likely to be met with.

This is well taken care of by the manufacturers of welding apparatus and welding material, and suitable rods for general brass and bronze welding can best be obtained from them. The best all-around welding material is manganese-bronze, although Tobin bronze may also be used with good results. The so-called manganese-bronze is really a manganese-brass, because the two principal ingredients are copper and zinc, the percentage of tin being quite small. Rolled manganese-bronze rod or wire is quite fluid and makes a very good weld. Tobin bronze is somewhat more fluid, and while, in many cases, it works well, yet if the melting point of the piece that is being welded is high, due to the presence of a considerable percentage of copper, it may be difficult to get the piece to melt at the same time as the welding-rod; manganese-bronze, not melting at quite so low a temperature, is, therefore, more satisfactory, as a general rule. Tobin bronze is really a Tobin brass, as it consists mostly of copper and zinc.

It should be understood that the percentage of the various elements in both manganese-bronze and Tobin bronze may vary considerably, so that they are not alloys of constant composition, the difference depending upon the ideas of the manufacturers; but both contain some iron, which appears to give greatly increased strength and makes the essential difference between the properties of these metals and ordinary brass. As all brasses contain zinc, which readily volatilizes under the heat of the torch, the advisability of having a considerable percentage of zinc in the welding-rod is apparent.

Manganese-bronze can be used in the form of $\frac{1}{4}$-inch sticks 12 inches long and can be made by any good brass foundry. For sheet brass, rolled manganese-bronze or Tobin bronze

rods of the proper size, $\frac{3}{16}$ or $\frac{1}{4}$ inch, are most satisfactory, as they make a little smoother weld and are more fluid. This fluidity is sometimes a disadvantage, particularly in welding on curved surfaces, and it is well to have the various kinds of welding-rods on hand, using the one that suits the case best. As far as strength is concerned, there appears to be no practical difference.

**Welding Material for Aluminum.** — For cast aluminum, an alloy of 93 per cent of aluminum and 7 per cent of copper, which is the standard No. 12 mixture, gives satisfactory results and can be cast by any good aluminum foundry in sticks $\frac{1}{4}$ inch in diameter and 12 inches long. It is convenient for small work to have sticks $\frac{3}{16}$ inch in diameter and sometimes for large work $\frac{3}{8}$ inch is better, but it is seldom that either of the two latter sizes is required. Of course, where large numbers of pieces of the same composition are to be welded, as in manufacturing work, the proper alloy, which will be nearly the same as the castings, should be used. But as it is not possible to know the composition of all alloys handled by a repair shop, one mixture, such as given above, has to be adopted as a compromise. For sheet aluminum, strips of the same metal are generally most satisfactory, although aluminum wire is frequently employed. Cast aluminum sticks cannot be used.

**Material for Welding Malleable Iron.** — In the case of thin sections of malleable iron which are of the "white-heart" variety, it is possible to weld them with regular steel welding-wire, and this should be attempted in such cases before anything else is done. In "black-heart" castings, the use of steel wire will simply result in the metal sticking to the wire and pulling away from the casting, the same as when it is attempted to use welding wire on cast iron. In addition to this, blow-holes apparently form in the piece. In cases where strength is not necessary, such as in filling holes or covering over defects, cast iron is the best material to use. It amalgamates quickly with the malleable iron and makes a good smooth job, but the chances are in favor of hard spots being produced, from the melted malleable iron becoming white or chilled iron on solidifying. For the majority of work, manganese-bronze is the best to use, and that coming in

rolled rods is most satisfactory. Properly used, a first-class job can be done, and, as the bronze is stronger than the malleable iron, the weld, if properly made, will give no trouble. Malleable iron should not be brought quite to the melting point, and, after a little experience, this can be determined with great accuracy. If it is hotter than this, it is detrimental to the strength of the casting. There are no two pieces of malleable iron alike; thus it is impossible to predict what the result will be before the welding is begun.

**Fluxes used for Oxy-acetylene Welding.** — Those who are familiar with oxy-acetylene welding are aware that fluxes, scaling powders, etc., are used; but it is not generally known why the use of these fluxes is necessary. They are sometimes used in the shape of powders into which the welding-rod is dipped, thereby transferring the flux to the weld; or they may be incorporated in the welding-rod itself. Also a special welding-rod containing certain elements may be used in connection with a powdered flux. Inasmuch as each metal has different characteristics and requires different treatment during the welding process, the nature of the flux varies with the metal. Therefore, it will be well to consider each metal separately, first explaining the nature of the difficulties encountered and then describing the remedies which are applied, including, as far as possible, the materials used for making the fluxes. It should be stated here that the manufacture of satisfactory fluxes requires considerable chemical knowledge and, in the majority of cases, should not be undertaken by a welding shop, because of the difficulty of obtaining the proper amount of the necessary elements and mixing them properly, and because it is cheaper, as a general rule, to buy the fluxes from the manufacturers than to attempt to make them.

**Flux for Cast Iron.** — Melted cast iron has a great affinity for oxygen, which combines with it to form an oxide of iron or slag. This affinity which molten iron possesses for oxygen is well illustrated by the amount of slag produced during the cutting of steel, this slag being oxide of iron. In the case of cast iron the oxide is lighter than the melted metal and does not melt

at quite so low a temperature. Being lighter, it rises to the surface, which makes it easier to dispose of. Many kinds of fluxes for cast iron are furnished by the manufacturers of welding apparatus, or by manufacturing chemists, which vary considerably in composition, but which, as far as the author's experience goes, differ but little in efficiency. The principle of all of them is to provide some chemical which, at the high temperature involved, will break up the oxide into its component parts.

For cast iron, a mixture of equal parts of carbonate of soda and bicarbonate of soda makes a very satisfactory flux. Ordinary washing soda is the name commonly given to a somewhat impure carbonate of soda. Bicarbonate of soda is ordinary baking soda. The carbonates can be obtained in a chemically pure condition from the manufacturers of chemicals, but the author finds no particular advantage in their use. A good way to prepare the flux is to grind the washing and baking sodas together in an ordinary meat grinder, passing the material through the hopper two or three times in order to secure a thorough mixture. Somewhat more of this mixture will be used in welding than would be the case if one of the higher priced fluxes was used; but as both ingredients are obtainable at any grocery store at a trifling cost, the difference in cost more than offsets the difference in the amount used. The action of the carbonates is to combine with the oxygen in the slag, releasing the iron and allowing the oxygen to pass off in the form of carbon monoxide or carbon dioxide.

It will be noticed, in the use of a cast-iron flux, that as soon as a small portion of it is put on the melted iron, the surface of the metal becomes clear and mirrorlike, and that, under such conditions, the union of the metal in the piece and the metal from the welding stick is easily made. The necessity of using a flux for cast iron may not be thoroughly appreciated, but if an attempt is made to weld cast iron without it, difficulties will at once be experienced.

**Steel and Wrought-iron Flux.** — In welding these metals, a flux is not ordinarily used, although there is a certain amount of oxide formed which may be removed by the use of a cast-iron

flux. The melting points of both soft steel and wrought iron are higher than the melting point of the oxide, and, while the oxide is lighter than the melted metal, there is more or less tendency for it to sink into the body of the weld. The judicious use of a small amount of flux will help this difficulty. In welding steel, however, the principal thing to guard against is burning the work, which no flux will overcome, and which ruins the weld beyond repair. While it is not necessary to use a flux in making ordinary steel welds, it is absolutely necessary to use the proper kind of welding-rod or wire. The higher the percentage of carbon in the steel, the greater is the danger of burning. The author does not believe it possible to burn wrought iron, which is simply steel with an exceedingly low percentage of carbon, the only difference between the two metals being due to the method of manufacture, which, in the case of wrought iron, naturally produces a metal with less carbon. Inasmuch as the welding-wire is generally of considerably smaller section than the weld, there is a greater liability of burning the wire than the weld. The proper manipulation of the torch will help to overcome trouble from this source, but the necessity of having a welding-rod that is not easily burnt is obvious, and, therefore, iron wire is used.

**Copper Welds.** — There is no necessity for using a flux for welding copper, if the surfaces are clean and if the proper welding-rod is used. Ordinary copper is quite free from impurities, because traces of such impurities make it impossible to use the copper. This metal, however, has several peculiar properties. When melted, it has a strong affinity for gases, such as hydrogen and carbon monoxide. Oxygen is also absorbed by the melted metal, producing copper oxide which forms a true alloy with the copper, making it brittle and worthless. When the metal solidifies, these occluded gases are given out, leaving the metal a mass of blow-holes. It is, therefore, necessary to provide something which has a greater affinity for oxygen than the copper. This is done by the use of phosphorus, which, instead of being used as a flux, is incorporated in the welding-rod. Only a small percentage of phosphorus is required, as none should remain in

the weld after it is made, although small traces of phosphorus in copper have no bad effect on its physical properties. It is evident that the production of such welding-rods or wire is a matter which should be left in the hands of competent manufacturers. This special copper-welding material can also be obtained from apparatus manufacturers.

**Fluxes for Copper Alloys.** — Theoretically, the fluxes for a copper alloy should depend upon the composition of the alloy, but, while there are some objections to it, for all practical purposes ordinary borax gives very good results. To prepare the borax for use, it should be melted and then allowed to cool, after which it is powdered, because in its original condition the borax does not lie quietly in the weld, but foams up and a great deal of it is wasted. It is the author's experience that greater success is obtained by using a satisfactory welding-rod for copper alloys than by varying the fluxes. When the composition of the piece being welded is unknown, the use of one flux may be satisfactory while another one is not. Borax seems to be the best all-around substitute. In welding brasses and bronzes, care should be taken not to heat the piece too hot. If carefully observed, it will be noticed that at a certain temperature the prepared surfaces will show little globules rising from them. The degree of temperature just a trifle above this point is the temperature at which the metal from the welding-rod should be added. It will be found that if this is done a satisfactory weld will be made, provided the surfaces are clean and a small amount of borax is used as a flux.

**Flux for Aluminum.** — At high temperatures aluminum has a strong affinity for oxygen. At ordinary temperatures pure aluminum is but little affected, but all ordinary aluminum pieces, which are generally alloys of aluminum and copper or of aluminum and zinc, tarnish more rapidly. The tarnish is due to the formation of a thin film of oxide of aluminum. Unlike iron or steel, where the oxidization or rusting goes on indefinitely, the thin film of oxide on the surface of aluminum protects the metal from further attack at ordinary temperatures. However, when aluminum is melted, it oxidizes freely, and as the

oxide or slag is heavier than the melted metal and melts at a very much higher temperature, the tendency is for it to become mixed with the molten metal and weaken the weld. This action of the oxide makes it very troublesome for a beginner to weld aluminum.

The chemical inertia of the oxide makes it exceedingly difficult to decompose with a flux, even at the temperature of melted aluminum. Fluxes for this purpose, therefore, have to be very strong and chemically active, and one difficulty with those which the author has used is the after-action on the aluminum, a large number of pieces having been observed in which the metal for some distance around the weld had been seriously injured by this action, although it took some time for the damage to develop. In some cases instructions are issued that, after the welding is done, the piece must be thoroughly brushed off with boiling water to remove the remnants of the flux and prevent this action. It is also the author's experience that, after a weld has been made with a flux, should a crack develop in it or near it, such a crack cannot be welded without considerable difficulty, if it can be welded at all, unless the surface is thoroughly cleaned and the metal in the old weld has been removed. Also, while it is theoretically advisable to use a flux, and while in the case of sheet aluminum it is necessary to do so, there are other reasons in the case of repairs to such castings as automobile crankcases, transmission cases, etc., why the use of a flux is difficult. The principal ones are the condition of the surface before welding, and the fact that it is not desirable, in the case of thin sections of aluminum, to prepare the piece by beveling it, as is done in the case of iron and steel. There is considerable shrinkage in an aluminum weld, and it is advisable to resist this as much as possible by leaving the full thickness of the section, the thin edge of a prepared piece having less area and, therefore, offering less resistance. Of course, this will not stop shrinkage entirely, but it helps to do so.

**Cleaning of Aluminum Work.** — Before any flux can be used, the surface must be entirely cleaned. Frequently, it is not possible to do this, although the use of strong acid and alkali, such as

hydrochloric acid and caustic soda (applied to the work separately), followed by a thorough washing and brushing in water afterward, will remove the grease and dirt from the exposed surfaces. It will not, however, remove the oxide nor, as a general rule, will it remove the grease and dirt from the crack or break, because they are more or less absorbed by the aluminum, which is porous. This absorption extends in some cases for quite a distance from the break, and, unless such metal is entirely cut out, the use of a flux will be found unsatisfactory. Of course, in some cases it is possible to spring a piece to allow for contraction, but in other cases this is not feasible and other remedies must be resorted to. The narrower the weld, the less the con-

**Table I. Composition of Flux for Welding Aluminum**

| Ingredients | Per Cent |
|---|---|
| Lithium chloride | 15 |
| Potassium chloride | 45 |
| Sodium chloride | 30 |
| Potassium fluoride | 7 |
| Potassium bisulphate | 3 |

traction and distortion of the piece, and so the less metal removed the better.

**Composition of Aluminum Fluxes.** — A number of fluxes are sold by the apparatus manufacturers and the chemical companies, which vary in composition, and these firms should be consulted as to the best flux to use, the conditions under which it is to be applied being thoroughly explained. Sheet aluminum work is generally a manufacturing proposition, sheet aluminum being used largely for automobile and carriage bodies and similar purposes. A flux is necessary for the proper performance of the work, but as the surfaces are clean the same objections to a flux do not exist as in the case of broken parts, and a proper flux will make the weld just as tough and capable of standing as much work as the original sheet. A flux which was devised in France in the laboratory of the Autogenous Welding Association has the composition given in Table I. A very small amount of this flux is all that is necessary, but it should be remembered

that it is necessary to wash the flux off carefully, as previously explained. This flux gives a bright red color to the flame when it is applied, which is characteristic of lithium salts. The author has used this flux and finds that, as would be suspected by one familiar with the chemical properties of its ingredients, it is exceedingly active. It is, however, open to the objections mentioned above. The composition of a number of other fluxes are given in Table II. Most of these are patented in Europe,

**Table II. Fluxes for Welding Aluminum**

| Sodium Chloride, Per Cent | Potassium Chloride, Per Cent | Lithium Chloride, Per Cent | Sodium Fluoride, Per Cent | Potassium Fluoride, Per Cent | Sodium Bisulphate, Per Cent | Potassium Bisulphate, Per Cent | Sodium Sulphate, Per Cent | Potassium Sulphate, Per Cent | Cryolite (Aluminum-sodium Fluoride), Per Cent |
|---|---|---|---|---|---|---|---|---|---|
| 30.0 | 45.0 | 15.0 | .. | 7 | 3 | .. | .. | .. | .. |
| .. | 33.4 | 33.3 | 33.3 | .. | .. | .. | .. | .. | .. |
| 12.5 | 62.7 | 20.8 | .. | .. | .. | 4 | .. | .. | .. |
| 16.0 | 79.0 | .. | .. | .. | .. | .. | .. | 5 | .. |
| 17.0 | 83.0 | .. | .. | .. | .. | .. | .. | .. | .. |
| 6.5 | 56.0 | 23.5 | .. | .. | .. | .. | 4 | .. | 10 |

in the country of their origin. As will be seen, the composition is a mixture of alkaline chlorides in various proportions. The melting point of the flux must be somewhat below that of the metal so that the former will melt and flux away the oxide just before the metal begins to flow. In actual use the flux powder is moistened down with alcohol. Otherwise it will be scattered by the draft from the blowpipe; in its dry form too the powder is very hygroscopic and liable to deteriorate, due to absorption of moisture. Another method employs the flux in the form of a core to the feeding stick which is made hollow for the purpose. This, as a rule, can only be used as supplementary to the flux pasted on the joint.

**Welding Aluminum without a Flux.** — In most cases, a weld can be made without the use of a flux in the time taken to prepare the piece so that a flux can be used. Therefore, for practical purposes, the use of a flux in other than special cases is believed by the author to be inadvisable, and a resort to the puddling of the weld with a rod made of soft steel about $\frac{3}{16}$ inch

in diameter and bent to the desired shape appears to be the best way out of the difficulty. It is true that more or less oxide is included in welds thus made, but the fact remains that they are strong enough for service and tests show that they are generally stronger than the surrounding metal. This being the case, it is evidently a question whether or not it is advisable to resort to the use of a flux. The puddling must be thoroughly done and care must be taken to keep the metal melted while it is

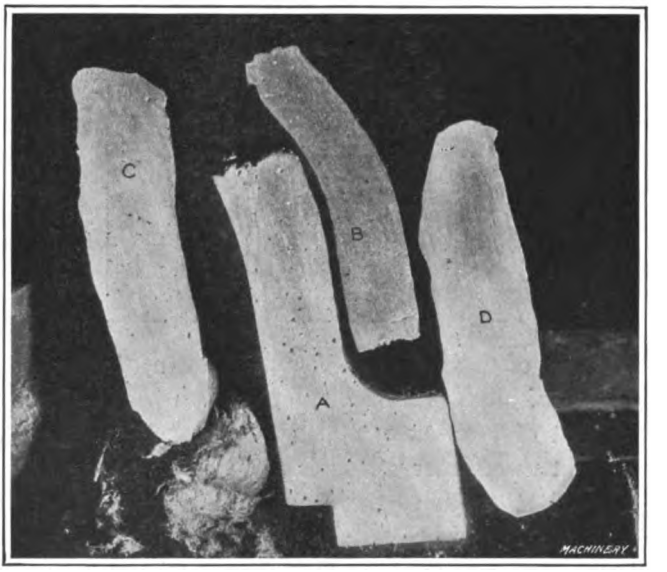


**Fig. 1. Polished Aluminum Surfaces. A shows a High-grade Casting before welding; B, C, and D show the Surface of another Piece of Aluminum — B before being welded, C after being welded by the Puddling Process, and D after being welded with a Flux**

going on; but if the proper precautions are observed there will be no serious defects visible in the weld through an ordinary magnifying glass, and the work will last as long as the original part.

Acquiring the necessary skill to enable one to make a satisfactory weld in this way takes time, and some men never become good aluminum welders. Close observation and the frequent breaking of test-pieces will show whether the necessary skill is

being acquired, and what is necessary to do in order to overcome any difficulties that may arise. There are two other points to be considered in connection with the use of an aluminum flux. First, there is no aluminum casting made that is not more or less porous, due to the presence of oxide in it. This being the case, the author does not see any use in trying to make the weld any better than the casting. Second, even by the use of a flux, it is not possible to make a perfectly sound weld, although, under the best conditions, it is somewhat freer from porosity than one

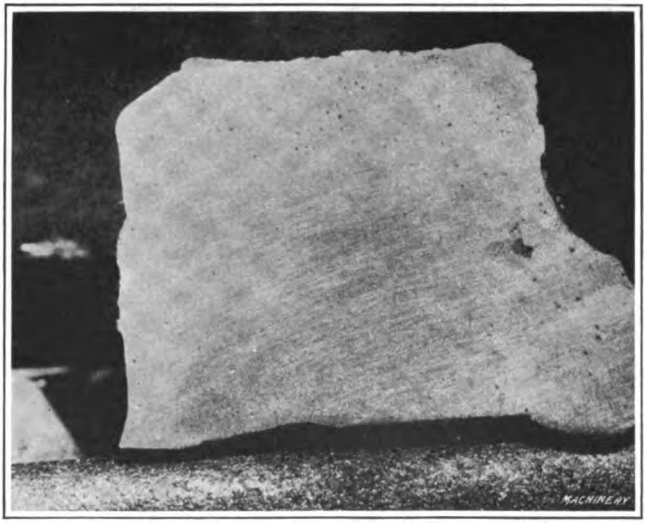

**Fig. 2. Section of a Boss built up in Aluminum by Puddling**

made without a flux. Therefore, the question of the use of a flux with aluminum castings is a practical one rather than theoretical, and in the author's mind the arguments against the use of a flux carry more weight than those in favor of it.

**Examples of Welds made with and without Flux.** — In support of the author's contention that a flux is not necessary in order to secure a satisfactory weld in aluminum, attention is called to the accompanying illustrations. In Fig. 1 it will be noticed that the defects in the original pieces of metal *A* and *B* are as bad or worse than in the puddled weld *C*, while even the weld *D*,

in which a flux was used, is not by any means perfect. Also, after comparing Figs. 2 and 3, it will again be noticed that while the flux does remove the defects to some extent, the weld so produced is not perfect by any means. It is almost too much to expect that in the operation of welding a flux can be made to penetrate to all parts of the weld and to come in contact with every particle of oxide, no matter how carefully the work is done. It should be stated that piece *A*, Fig. 1, was taken from the trans-

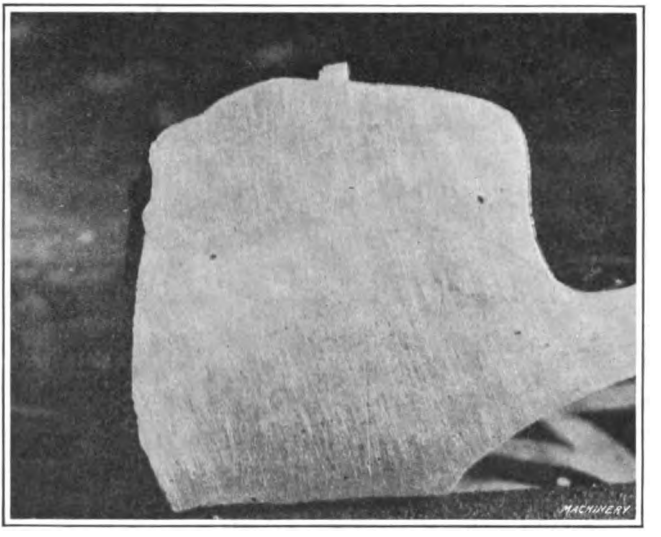


**Fig. 3. Section of a Boss built up in Aluminum by Welding with a Flux**

mission case of one of the best automobiles manufactured in the United States, and was selected with a view of obtaining as good a piece of aluminum as possible. The quality of the metal was so good, and it welded so nicely, that the man doing the work commented on it by saying, "This is *aluminum*," his meaning being obvious.

**Aluminum Alloys.** — The principal alloys used in the United States for aluminum castings that the ordinary repair welding shop meets with are composed of about 93 per cent of aluminum and 7 per cent of copper; while in England and on the Continent the general alloy appears to be about 90 per cent of aluminum

and 10 per cent of zinc. In both cases, other elements are present in small quantities. The zinc alloy is somewhat stronger at ordinary temperatures than the copper alloy, but has the peculiar disadvantage of being very brittle at a temperature just below the solidification point. This makes it difficult to cast, particularly if the pieces are of a complicated shape; but while a welder may encounter some of these zinc alloys, particularly in parts cast a number of years ago, at the present time he will find but few of them. This is considerably to his advantage, because it is sometimes very difficult to weld an aluminum-zinc alloy on account of the tendency of the shrinkage strains to crack the metal. The author has frequently found it necessary in such cases to purposely cut the casting at a point where it can be sprung to compensate for the shrinkage, but in several cases has found it impossible, even by doing this, to avoid cracking. A zinc alloy can generally be readily detected by the condensation of the white fumes of oxide of zinc on the colder parts of the casting. In such cases thoroughly preheating the whole piece to the highest safe temperature undoubtedly helps to reduce the shrinkage strains.

**Constitution of Malleable Iron.** — This metal is a very peculiar one, and, on account of its method of manufacture, but little is generally known of its peculiarities and characteristics. Gray cast iron contains carbon in two states; in one case, it is combined chemically with some of the iron in the form of carbide of iron, a hard, white, brittle, and weak substance. In the other form, the carbon exists as free graphite, which is in the form of thin plates or flakes which break up the continuity of the iron, and its presence largely accounts for the comparatively low strength of cast iron. White iron or chilled iron has no free carbon in it, all of the carbon existing in the combined state as carbide of iron. Malleable iron is manufactured by packing the castings, which are made of white cast iron, in boxes filled with some pulverized material such as iron ore, lime, or sand, and subjecting them to a high temperature for several days, so that some of the combined carbon is partly removed by being oxidized; but it is mostly changed into a third condition, which

is called "temper carbon." This latter change cannot take place in the presence of any appreciable amount of graphite, which is the reason for using white iron in the process. This temper carbon is chemically and physically the same as the graphite before mentioned, but it is present in the form of small rounded masses, which do not detract from the strength of the material, as do the plates of graphite in gray cast iron. It is not necessary to go further into the metallurgy of malleable iron, except to say that the quality of a malleable-iron casting depends upon the material in which it is packed during the annealing process, on the time to which it is subjected to the heat, on the temperature, and on the original quality of the material from which it is made. If the casting is small, if it is packed in such a material as iron oxide, and if it is subjected for a long enough time to a sufficiently high temperature, a large percentage of the carbon may be eliminated, resulting in the formation of a crude steel. Such castings can be welded with ordinary steel welding-wire and very good results obtained. In a thick casting, however, particularly if it is not packed in iron oxide or some similar material, the action is different, and the resulting metal is not a crude steel but a form of cast iron, except on the outside, where there will be a thin layer of the steel formation. A welder who observes closely will notice that such a casting acts peculiarly. The outside skin is hard to melt and acts as steel does under the torch; while the center part acts more like cast iron, becomes full of blow-holes, and cannot be welded with steel, but will weld readily with cast iron, as in fact the whole section will do. At times, such a weld is strong enough, but it has only the strength of the cast iron and will tend to be extremely hard.

A little consideration will show why this is naturally the case. The original metal of which the casting was made was cast iron of such a composition that it chills, even when poured in sand without a chill plate, so that the melting of the malleable iron tends to return it to its original condition of chilled or white cast iron, which is very hard and brittle. This accounts for the hard spots and brittleness of a malleable-iron weld made with

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malleable-iron welding-rods. Of course, it is possible to eliminate these difficulties by again putting the piece through the malleabilizing process, but this is not possible in ordinary repair work, so that other means must be resorted to for joining the broken parts. It is impossible, therefore, to produce a truly homogeneous weld in malleable iron without putting it through the malleabilizing process. Experience has shown that the most satisfactory and practical way of joining broken malleable-iron parts is, as already mentioned, by using manganese-bronze of the proper composition. Care should be taken not to heat the malleable iron too hot, and it must not be melted, but only brought to the temperature at which the bronze will alloy with it, and the weld should be somewhat reinforced. Borax used as a flux gives very good results.

**General Remarks on Fluxes.** — It should be remembered in all discussions of fluxes that the flux used depends upon the kind of welding material used and *vice versa*, as well as on the material which is being welded; so that no general rules can be laid down governing all cases. More or less experimenting has to be done by every welding shop, particularly by beginners, because they are not able to reproduce at will the same conditions in the use of the torch; and the variations existing from this cause frequently overshadow or entirely obliterate the results obtained by the use of certain fluxes and welding materials. The preceding outline, however, is the result of the author's experience during the past six years in welding over 22,000 pieces of all kinds and qualities of metal. That there will be changes in the practice of oxy-acetylene welding is undoubted. That new methods will be discovered is not questioned, as it is not to be expected that any process of so recent an origin as oxy-acetylene welding is fully developed. However, the author believes that the composition of fluxes and welding materials should be determined in laboratories equipped for accurate work, and that rough experimenting without facilities for properly checking and determining the results is a detriment rather than a benefit to the art. He therefore recommends that, except where it is specifically stated above, fluxes and welding materials

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be either purchased from the manufacturers or from those furnishing the apparatus, and that time and money be not wasted in making experiments that have probably been made before by others better fitted to interpret the results.

# CHAPTER IV

## MAKING OXY-ACETYLENE WELDS

A BRIEF review of the practice of making oxy-acetylene welds may be of value at this point. The details are referred to in other chapters, but the general principles should be thoroughly understood. To become proficient in the art of autogenous welding requires experience and practice, but a knowledge of some of the fundamental principles will enable the operator to make more rapid progress. It is advisable to begin by welding cast iron, and then thin strips of iron or steel not over $\frac{1}{8}$ inch in thickness. Such thin strips can be welded without the addition of a filling-in material; the torch should be given a rotary motion accompanied by a slight upward and forward movement with each rotation. This movement tends to blend the metal and reduces the liability of overheating. If comparatively thick materials are to be welded, the edges should be beveled (by chipping, or in any other convenient way), as already mentioned. The beveled surfaces are then heated by a circular movement of the flame, care being taken to melt them to a soft, plastic state without burning the metal. Wherever fusion occurs, new metal should be added from a welding-rod, the composition of which is suitable for the work in hand. In continuing the heating operation, the flame should be swung around in rather small circles and be advanced slowly to distribute the heat and prevent burning. The surface should be thoroughly fused before adding metal from the welding stick, and the latter should be held close to, or in contact with, the surface. The heat is then radiated from the welding-rod to the work, whereas, if the metal were allowed to drop through the flame, it might be burned to an injurious extent. When the weld is completed, it is advisable to pass the torch over it, so that all parts will cool from a nearly uniform temperature.

When welding parts together, it is important not to heat one more than the others, because the hottest piece will expand most and the weld may crack in cooling as the result of uneven contraction. When making heavy welds, the parts should be brought to a red heat for a distance of about three times the thickness on each side of the weld, for thicknesses up to one inch, the distance being increased somewhat for heavier parts.

**General Rules for Welding.** — There are a number of points to be considered in oxy-acetylene welding, which apply equally to the welding of all metals. These will now be considered, and in subsequent chapters the special points applying individually to each metal will receive attention. Some of the instructions may seem unnecessarily minute, and even superfluous, but the author has obtained the best results by adhering closely to the rules laid down.

1. Follow strictly and without deviation the instructions given by the manufacturers of the apparatus used, in every respect. Reputable manufacturers, the only ones whose apparatus should be purchased, are not only willing, but anxious, to assist when difficulties are encountered. These manufacturers have spent thousands of dollars to find out how to handle their apparatus, and it is to be assumed that they know the best way and instruct accordingly.

2. Remember that a welding torch is an instrument of precision, and handle it as such. Throwing it down on a table, dropping it on the floor, or other misuse, will result in more or less injury to the welds made. If the torch tip becomes hot, do not plunge the whole head in water. Cool off the tip first. When it is thoroughly cool, the head may be cooled off. Lack of attention to this point in certain types of torches will damage the end of the tip in the head, and may cause injury to the threads in the head, when the tip is removed.

3. Keep the torch in first-class condition, free from leaks, and with clean tips. See that the gages register properly at all times, and that the reducing valves act promptly. Good results cannot be obtained with defective apparatus. See that all joints are tight, so that neither acetylene nor oxygen may be wasted. An

oxygen leak may not seem very dangerous, but it may result in a rapid burning of the welder's clothes or cause some wooden article to burn where a spark falls on it, when otherwise no damage would result. An acetylene leak is dangerous. If it were generally appreciated that a quart can filled with an explosive mixture of acetylene and air has enough potential energy to kill a person near by, no acetylene leaks would be permitted. Be particularly careful to see that no leaks exist in the hose or torch. The hose on the floor is liable to have pieces of metal dropped on it which damage it, and even with the best of care it will in the course of time wear out, the inner lining becoming porous and allowing the escape of the gases. Hose in this condition cannot be repaired; it is dangerous and should be replaced at once. Leaks around the torch are liable to burn the welder and cause explosions, and should not be tolerated.

4. Adhere strictly to the pressures specified by the manufacturer for the different sizes of tips. Do not attempt to force the tip by increasing the gas pressure to obtain a larger flame, but use a larger size of tip. The excess of oxygen caused by the forcing of the tip will result in decreasing the strength of steel welds and will damage other welds seriously. This is a point which is generally overlooked, but which is exceedingly important. Use a tip large enough to do the work easily, but under no circumstances use too large a one, as damage to the weld will probably result.

5. Unless otherwise specified, always use a neutral flame. The flame of a torch may contain an excess of acetylene or an excess of oxygen, or it may be strictly neutral. It is not to be understood by the expression "neutral" that one torch may not consume more oxygen than another, even when the flames appear neutral in both cases. The neutrality of the flame refers to the small welding flame only, and simply indicates that to the eye the flame has just sufficient oxygen to burn the acetylene completely and no more. If care is not used, a considerable amount of oxygen, over and above this requirement, may escape through the torch tip and damage the weld.

6. Always light the acetylene first and turn it off last. In

some types of torches, this may avoid an explosion or "back-fire," which, while it may cause no damage, is to be avoided whenever possible. Back-fire, as it is commonly called, is really a burning of the acetylene inside of the torch. This is accompanied by a deposit of soot which may collect in the small passages and prevent the torch from working satisfactorily. If this is the case, the passages will have to be cleaned out, although sometimes the deposit will burn out after a short period of use. The temporary reduction in the size of the welding flame, however, tends to make a bad mixture, with resulting damage to

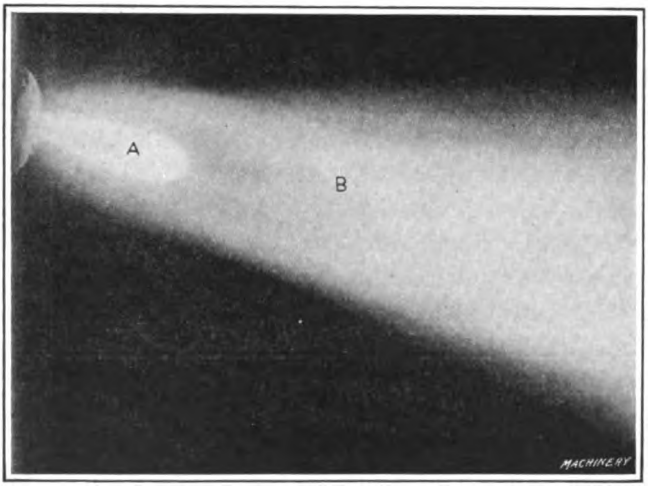



**Fig. 1. Neutral Flame enlarged about Three Times**

the weld. Never use any oil or grease around a torch nor around anything exposed to the action of oxygen. Fires may result from this, as the oil is rapidly oxidized with a considerable increase of temperature.

7. It may seem superfluous to mention that an acetylene leak, particularly in a generator, should not be stopped by attempting to weld it, or by using any heat at all; but there has been at least one case of this kind which resulted in the explosion of the generator and the instant death of the man who attempted to weld it.

8. In case repairs are needed on the torch, it is best to send it

to the manufacturers. A mechanic familiar with the construction can, of course, make repairs, but the relation of the sizes of the passages to each other must be maintained for efficient work, and the manufacturer can do this best.

9. Never use copper tubing for acetylene piping. It is easily attacked by acetylene, at least under certain conditions, and an explosive compound is created which detonates at the least shock.

**The Oxy-acetylene Flame.** — Fig. 1 shows a photograph of the neutral flame as it appears to the eye, but magnified three

**Fig. 2. Neutral Flame photographed through a Light Filter**

times. The length is about three times the diameter of the largest part; the small, intensely white flame *A* is sharp in outline, and is symmetrical and smooth. A jagged or irregular flame indicates that the hole in the end of the tip is not true, or is rough; it is necessary occasionally to run a drill of the exact size carefully into this end and to clean it out and true it up. The use of a soft wire has been advised for this purpose; but it is not possible to obtain good results in this way. The thinner flame *B*, as it appears in the illustration, is due to the burning of the hydrogen left when the acetylene is broken up into its constituents, carbon and hydrogen. The fact that the

photograph was given a one-minute exposure with a very rapid plate shows that the conditions were not very different during that time, because of the sharp outlines of both flames. It might be stated that this stability of the flame is characteristic of the torch used to produce the photograph.

Fig. 2 shows the correct shape of the neutral flame. This photograph was taken with quite a long exposure through a light filter, the conditions not being changed in any way from those under which Fig. 1 was taken. It will be noticed that, while the flame is of the same length, the width has been reduced;

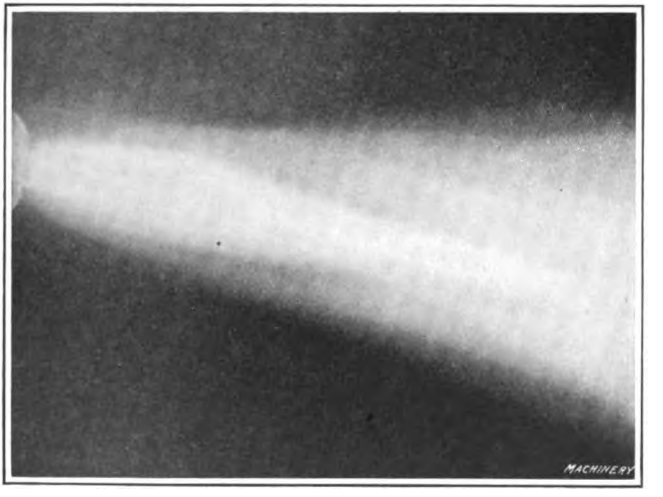



**Fig. 3. Appearance of Flame with an Excess of Acetylene**

the hydrogen flame has practically disappeared. It will be also noticed that there is a considerable halo on both sides of the flame, which the author believes is caused by a small amount of acetylene which escapes without combining directly with the oxygen, and which is probably burnt by oxygen from the surrounding air. It will be noticed that there is none of this halo at the end of the flame. This, however, does not now appear to be of serious importance from the practical side of welding.

In Fig. 3 it will be noticed that the neutral flame has entirely disappeared and in its place is a longer white flame, character-

istic of an excess of acetylene. When the acetylene is reduced, or the oxygen increased, this flame decreases in size and becomes sharply defined, this being the neutral flame. Upon a further increase of oxygen with no change in the acetylene, this sharply defined neutral flame becomes somewhat shorter and takes on a violet tint which indicates a surplus of oxygen in the flame itself. If the increase of oxygen continues, the flame will be blown out. This excess-of-oxygen flame is shown in Fig. 4, and it will be noticed that it is shorter than the neutral flame and also smaller in diameter, and that it has a bulbous enlarge-

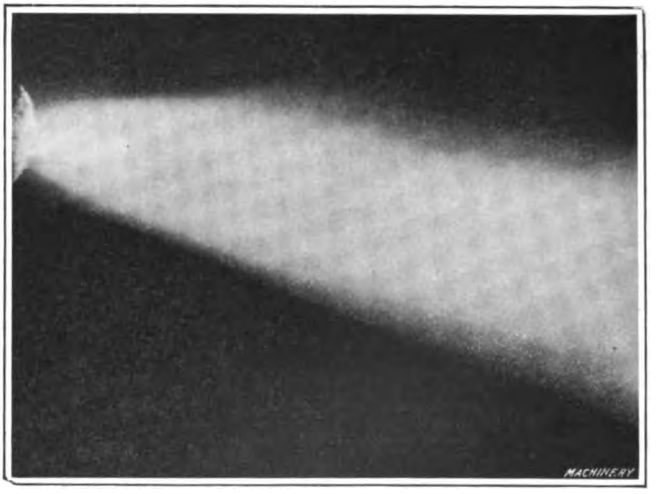



**Fig. 4. Appearance of Flame with an Excess of Oxygen**

ment at the end, while the neutral flame, as it appears to the eye, is more elliptical. It will also be noticed that the outline of this flame is sharper. The hydrogen flame has a peculiar shape at the top. The cause of this is not at present known, but it is probably due to the peculiar shape of the small flame, which is not symmetrical. It is believed that this is the first time that photographs of the various flames have been published, and their appearance indicates the necessity of further study of them. For the present purpose, it is enough to show them as they actually appear.

**The Neutral Flame.** — All instructions as to the operation of welding torches or blowpipes explain how a neutral flame is produced and state that, when the oxygen pressure is turned on sufficiently to just destroy the double cone produced by a deficiency of oxygen, the flame is neutral. It is evident that with a given acetylene pressure in a given torch only one oxygen pressure will produce this result, and that if the acetylene pressure be varied, the oxygen pressure must also be varied, so that with any torch a large number of neutral flames is possible. The author does not know of any tests having been made to prove that the flame is really neutral, that is, that there is no excess of oxygen or acetylene in or surrounding the flame. Neither does he know of any accurate tests made as to the relative amounts of oxygen and acetylene consumed by any type or design of torch, and believes that such tests would be quite difficult to make. Theoretically, one volume of oxygen is necessary in a torch to burn one volume of acetylene, both being pure. Inasmuch as neither oxygen nor acetylene is ever absolutely pure, and as it is impossible to produce in any torch theoretically perfect conditions, any claim that torches can be so made as to consume equal volumes of oxygen and acetylene appears to be unfounded. It would also appear that the question of the real neutrality of the flame is one that is still open for serious investigation. In spite of these difficulties, it has been amply proved in practice that a torch of good design, used as instructed by the manufacturers, and with a neutral flame produced with the pressures for which the torch is designed, will give satisfactory results, and these matters are referred to only for the purpose of making clear some things that are generally much misunderstood.

## CHAPTER V

### OXY-ACETYLENE WELDING OF CAST IRON

CAST iron is the easiest metal to weld, and, therefore, should be the first one tried by the beginner. It is best to begin with small pieces, say, $\frac{3}{8}$ by 2 inches in section. Bevel both sides of the two pieces so that the included angle is about 90 degrees (see Fig. 2, Chapter II) and grind off the sand, scale, and dirt for about $\frac{1}{2}$ inch away from the V. Set the ends about $\frac{1}{32}$ inch apart, and somewhat above the surface of the table, say, on two V-blocks of the same thickness.

**Making the Weld.** — Use the size of tip recommended by the manufacturer, adjust the flame to neutral, and bring both edges to a bright red; then melt down the bottom of the V, applying a little flux or scaling powder with the heated end of the filling rod. Do not add any metal from the filling rod until the bottom of the V is filled from the sides. Be sure that the metal runs together freely. When ready to add metal, put the end of the filling rod in the melted metal of the weld and play the flame on both the rod and the weld so that the metal runs together. As often as is necessary, dip the rod in the scaling powder and proceed with the filling in. Be careful not to add too much at one time, using just enough to make the metal run freely. The weld should be made in steps. If too much metal is added in one place, it is likely to run over into the bottom of the V, and, unless the welder is experienced and careful, will cause a cold shut which makes a defective weld. As the filling progresses, be sure that the metal is welded at both sides. Most welders are right-handed and the tendency is to get the left side of the weld well made, while the right side is likely to be "cold-shut" on account of sufficient heat not being applied at that point. The "feel" of the torch in the hand turns the tip toward the left rather than the right. Left-handed welders, therefore, will do

just the reverse. This is a point of great importance, and many defective welds, especially in heavy sections, are due to neglect of this precaution.

After all the metal necessary has been added (it should be enough to raise the weld slightly above the surrounding surface), play the torch flame at the junction of the old and new metal until the new metal runs into the old. At this time, do not add any scaling powder. If this is done properly, and it should, in fact, be done at intervals, as the weld progresses, there will be no hard spots at the junction. These hard spots are caused by the melted metal striking a colder surface and chilling. They may be caused, even with the utmost care on the part of the welder, by unsatisfactory welding material, but with good material and care they will not exist. The scaling powder has nothing to do with them, but does at times, if of certain compositions, produce a thin intensely hard scale, which, however, is readily removed by chipping or grinding.

It should be remembered that the beginning and end of a weld require less heat than the middle, because there is not the amount of metal present to absorb the heat, and unless care is taken to keep the torch somewhat away from the metal at the beginning and end, the tendency will be to burn it; also, at these points, in the case of cast iron, there is a tendency for the metal to run away, and when adding metal there, the torch flame should be directed toward the center of the piece rather than toward the edge. It will also be found best to use but little scaling powder, as the slag which forms on the surface of the iron tends to hold the melted metal in place. In many cases, the welding-rod can be held close to the edge, and by manipulating it and the torch the metal will be held in place.

After one side is welded, turn the work over and repeat the operation on the other side, beginning where the weld on the first side ended; this saves gas. After the sides are welded, it is advisable to touch up the edges so that the metal will be welded entirely through the V's. Enough metal should be added so that the piece will "square up" when ground to its original size, and care should be taken that it does not run away. Evi-

dently the full heat of the torch is not needed at these points. In the case of a small weld like the one described, there will probably be no casting strains. It is advisable, however, to take the precaution of heating the weld uniformly in order to be sure that this difficulty does not exist. After the weld is finished, allow it to cool off in a dry, warm place.

**Finishing and Testing the Weld.** — When cold, grind or otherwise remove the surplus metal to the same size as the origi-

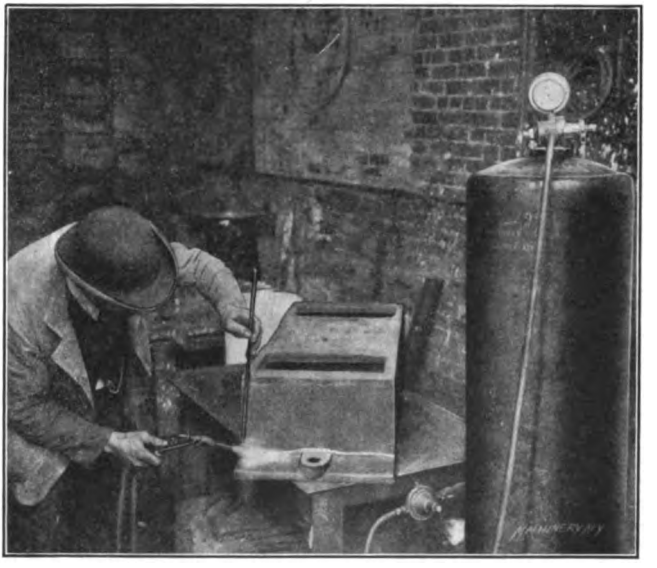


**Fig. 1. Welding the Broken Flange of a Cast-iron Base. The Operator feeds the Joint with a Cast-iron Rod**

nal casting, and put it in a vise with the top of the jaws at the center of the weld. If the weld has been properly made, it will be found impossible to break the piece with a hammer, except outside of the weld. It should be necessary to break off the piece at both ends of the weld and then break the weld crosswise (or lengthwise of the original piece) to see what the fracture looks like. If this is done, it will be noticed that the weld merges into the original metal without any distinct line of demarcation, and that the grain of the weld is somewhat finer than that of the casting; also that the color is slightly different, being gener-

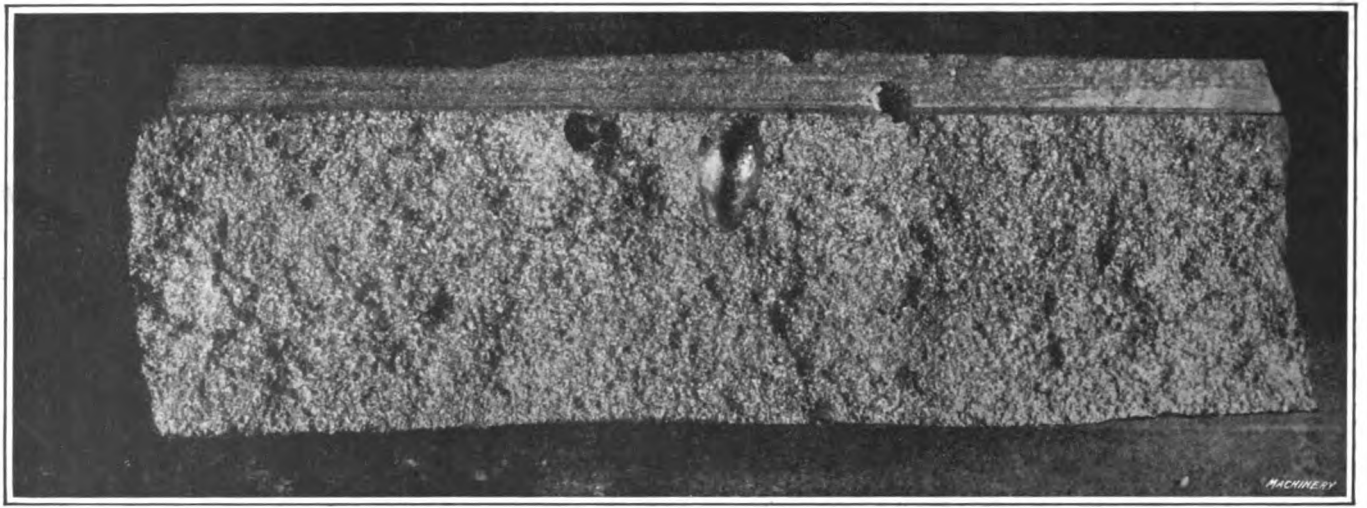



Fig. 2. Section of Cast-iron Weld broken at Right Angles to Line of Weld and magnified about Three Times. Note Uniformity in Grain of Iron

ally a trifle darker. The finer grain is due to the fact that the metal is added in small quantities, and, therefore, cools more quickly than the original casting, which produces a finer grain. In a properly made weld, the V should be much wider than the one made in the preparation before welding, because of the melting down of the sides. The difference in color is due to the difference in quality between the filling rod and the casting, and to the finer grain.

Fig. 2 shows the uniformity of structure of a properly made cast-iron weld. There is a slight difference in the size of the grains between the center where the weld

is, and the body of the casting, the latter being somewhat larger. This difference is more noticeable in a larger piece, and is more apparent in the piece itself than in the illustration. There is a small projection just to the left of the center of the large blow-hole, which is a particle of foreign matter, probably sand, that gave off enough gas to produce a blow-hole. This can be eliminated in welding by melting to the bottom of the hole and floating the dirt to the surface.

**Fig. 3. Weld in Cast Iron beveled from One Side. Top of Weld**

The first piece welded by a beginner will probably show defects caused by the metal not being thoroughly melted and only sticking together in some places instead of being solid. The only way to gain experience is to break a considerable number of pieces and repeat the trials until a sound weld is easily made. The difficulty in making sound welds increases with the size of the piece, and until one is sure that he can make good welds in small pieces, he should not try large ones. It may also be found that the proper size of tip is not used. Too small a tip will result in cold shuts and slow work. Too large a tip will result in blowing the metal away on account of the higher oxygen pressure used, which also makes the work slow, and tends to burn out the carbon and silicon in the iron, making it hard and brittle. The proper size of tip can be found after a few trials, and experience will soon teach a welder what tip to use without trial.

**General Precautions in Welding.** — In making welds in cast iron, special attention should be paid to these points: Preheat the work, unless it is a small piece, or of very simple form, for reasons already explained in Chapter II. Add scaling powder

only when the metal does not flow well, and even then use no more than necessary. Do not attempt to reweld pieces that have been previously welded or brazed, without first cutting away all of the old metal. When the weld is finished, cover it and allow it to cool as slowly as possible. In repair work, when beveling the edges, it is sometimes well to leave a few small points of contact for aligning the broken parts in the original position.

**Defects in Cast-iron Welds.** — As an illustration of the defects that are likely to occur in a cast-iron weld, the piece shown in Figs. 3 to 6 was prepared — the beveling being done from one side only, and the piece nicked with a hacksaw and broken in order to show the defects more clearly. Fig. 3 shows the front of the weld or the top as the work was being done, and shows how the weld should be made in steps in order to prevent cold shuts. The steps extend from *A* to *B*, the portion from *B* to *C* being welded entirely through, some of the metal hanging from the bottom of the weld in drops. Fig. 4 shows the back of the weld, and it will be noticed that from *A* to *B* the original break remains, while from *B* to *C* it has disappeared. In this view, it would appear that the weld is very nearly through, but, upon examining Fig. 5, it will be found that it is not through by about $\frac{1}{8}$ inch, due to the bridging action of the melted metal heretofore referred to. This is the real danger of a weld that is not burnt through. It is apparently sound, but really the condition is much worse than it appears. It will be seen, however, that where the metal has been burnt through, the weld is perfectly sound. At *C*, Figs. 5 and 6, will be seen a spot where the metal

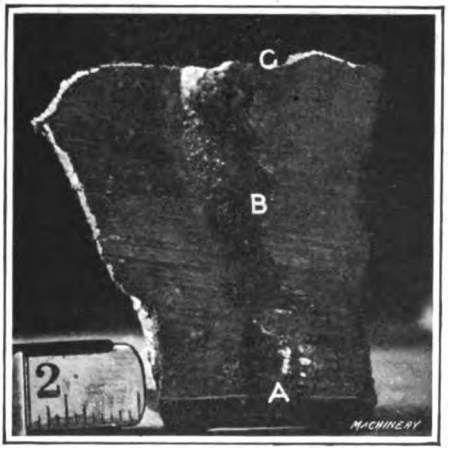



**Fig. 4. Weld in Cast Iron beveled from One Side. Bottom of Weld**

has run over from the added material, forming a cold shut, which is very distinct, and, of course, a serious source of weakness. In addition to the above, it will be seen that the weld is full of blow-holes for some distance from the bottom of the V. These were caused by adding metal before the pieces were thoroughly hot. The part of the weld which is level with the original pieces is sound at the top, which is proof that while a weld may be sound to all appearances, it may be very far from sound inside.

**Example of Cast-iron Welds.** — Fig. 7 shows a cast-iron exhaust manifold with one of the bolting lugs broken off. This is quite a frequent occurrence, and is generally due to the sharp corner left when the nut-side of the lug is machined. In order to keep the broken lug straight with the rest of the face, a planed piece of cast iron is clamped across the face, as shown. It is best to weld the back of the lug first on both sides of the clamp, going almost through. Then the clamps and block can be removed and the job finished.

**Fig. 6. Weld in Cast Iron beveled from One Side, but Broken, showing Defects**

It is easier in many cases to hold such pieces in a vise than to block them up on the table. After the weld is made on the outside, the inside should be finished, care being taken to burn out all remnants of the crack. The last thing done should be the finishing of the faces, and care should be taken to avoid hard spots. If it should so happen that the lug does not come true after the weld is finished (this should be tested with a straightedge), a small amount of metal can be added so that there is sufficient stock to grind and file. The finished weld is shown in Fig. 8.

**Repairing a Machine Frame.** — Fig. 9 shows the frame of a machine in which the break *B* occurred close to a babbitt bearing

*A*. It was decided to save this bearing if possible, as there would have been considerable expense in renewing it, not so much on account of the babbitt, as because of the difficulty of alignment. No finishing was necessary at the weld. This made it much easier to save the babbitt, because even if a few hard spots did

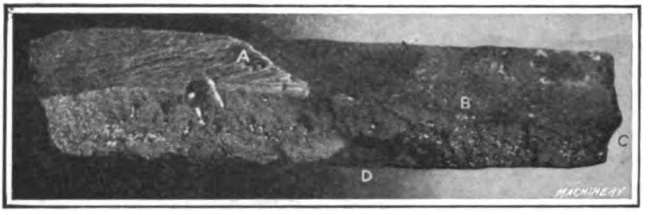



**Fig. 6. One of the Pieces in Fig. 5 magnified about Three Times**

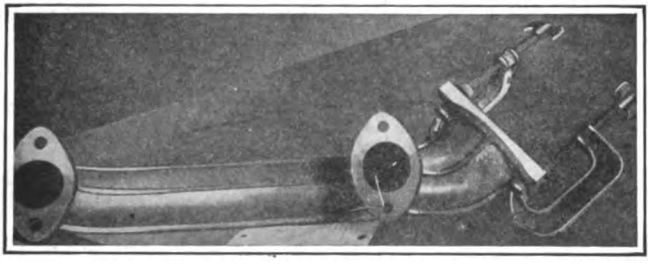


**Fig. 7. Cast-iron Manifold on which Broken Lug is to be welded**

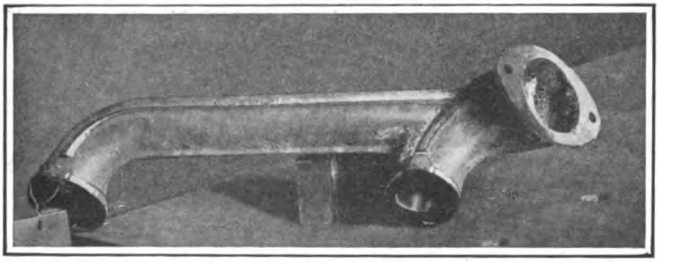


**Fig. 8. Completed Weld of Manifold shown in Fig. 7**

exist at the weld, it would make no difference. The casting was laid flat on the table, the parts lined up after preparation, and preheated with a Bunsen burner, during which time wet crushed asbestos was kept on both the top and bottom of the babbitt bearing. At frequent intervals water was poured on the asbestos

to keep it wet. As soon as the casting had been well warmed, the weld was made on one side, using a heavy tip, which was necessary on account of the absorption of heat by the cool metal. After the first side was finished, the work was turned over, repacked in wet asbestos, and the weld completed. The weld was then heated uniformly its entire length with the torch and allowed to cool in the air. Had the break occurred at about the place where the rule is shown, it would have been impossible to save the babbitted bearing, and an entirely different procedure would have had to be followed. Undoubtedly the babbitt would have been melted out and care would have had to be taken to allow for the contraction of the weld. Two torches would have been advisable, welding both breaks at the same time.

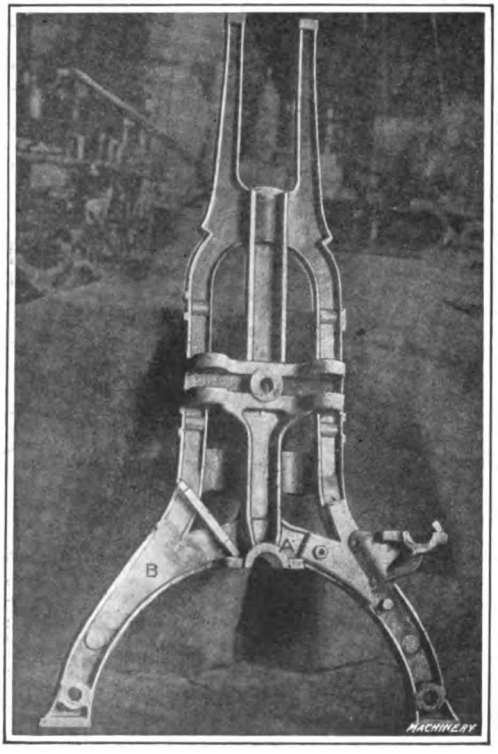



**Fig. 9. Machine Frame with Babbitted Bearing close to Weld**

**Welding a Cast-iron Crankcase.** — Figs. 10 to 14 show a large cast-iron crankcase of the barrel type, with a piece broken out and missing. Fig. 10 shows the preparation of the edges, which was done prior to making the pattern for the missing piece. This is permissible in this instance, because the metal is cast iron and somewhat over $\frac{1}{4}$ inch in thickness, and also because the new casting used in repairing was made with enough stock on

it to allow for finishing on the hand-hole face. Fig. 11 shows the asbestos backing for the pattern, supported by a sheet of iron and a mandrel through the camshaft bearing holes, this being an easy way of supporting the backing in this case. Broken-up asbestos paper is now used altogether in the author's shops for the purpose indicated, on account of the ease and rapidity

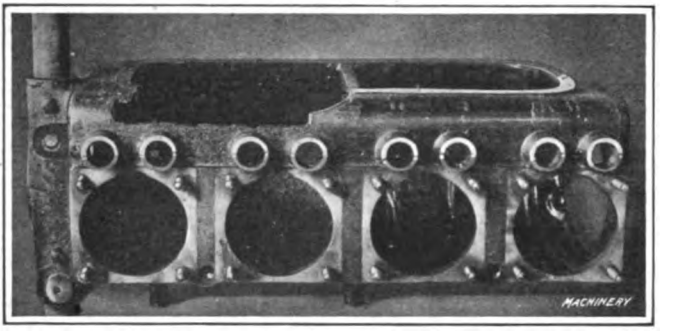



**Fig. 10. Cast-iron Crankcase in which Broken-out Piece is Missing**

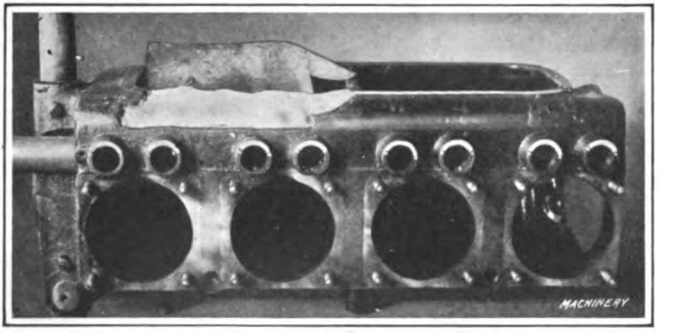



**Fig. 11. Asbestos Backing for Plaster-of-paris Pattern in Place in Casting shown in Fig. 10**

with which it can be applied. Prior to its adoption, it was the custom to use plaster-of-paris, trimming it off to the inside surface of the pattern it was desired to make. The asbestos used is soaked in water and squeezed out until it is just plastic. It is then pressed into place and smoothed down uniformly to the desired level. A sheet of tissue paper is then placed on it and oiled to prevent the plaster-of-paris used for the pattern

from sticking to it. The plaster-of-paris is next poured into place, and, as it gradually hardens, it is brought to the required contour and allowed to dry. The result is shown in Fig. 13, in which it will be noted that sufficient stock for finishing has been left on the hand-hole face of the casting, and that the plaster-of-paris, while hardening, has been beveled out to make the V. A gentle tapping on the casting around the pattern loosens it, so that it may be lifted out without breakage. Care should be exercised at this stage of the operation, and the plaster-of-paris should be allowed to become quite hard, although it need not be entirely dry. Upon removal, air-holes and irregularities on the inside face will be found, and they should be filled

**Fig. 12. Casting that is to be inserted in Place of Broken-out Piece in Fig. 10**

up. Attention should also be paid to so making the pattern that it can be drawn from the sand.

The casting made from this pattern is shown in Fig. 12, and the welded job in Fig. 14. This job was welded in a large forge, the break being turned downward into a charcoal fire, allowed to become nearly red-hot, turned over, carefully covered with asbestos paper and welded, but only from the outside, as it was not necessary from the standpoint of strength to do more than this. The weld, of course, was made entirely through the section, and what beads resulted were chipped off after the case was cold. After welding, the weld was turned into the fire again, allowed to come to a uniform temperature, and then packed in asbestos to cool. In this instance it was not necessary to heat the entire casting to the same high temperature, but the casting was all hot, the coolest part being at a temperature much above that of boiling water. It is one of the instances where it is not necessary to heat the whole casting to as high a temperature as the part to be welded, nor indeed is it desirable to do so. The case is stiff enough to gradually force the contraction to take place in

the weld as it is made, and, by allowing it to come to a uniform high temperature after the weld is finished, any strains that may be caused in welding are eliminated.

**Welding a Shaper Rocker Arm.** — Fig. 15 shows a cast-iron arm from a shaper. An attempt was made to weld this arm by someone without either the necessary knowledge or facilities, with unsatisfactory results. The weld at *A* and the opening at *B* showed that the weld did not extend in more than $\frac{1}{2}$ inch.

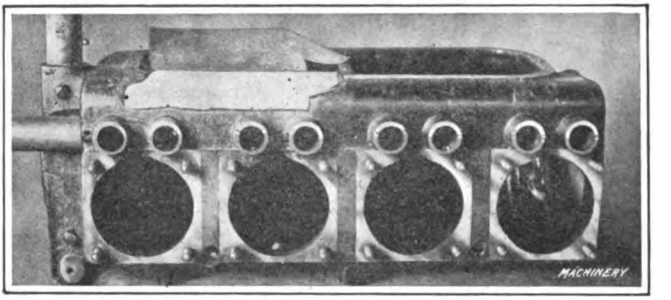



**Fig. 13. Plaster-of-paris Pattern Completed**

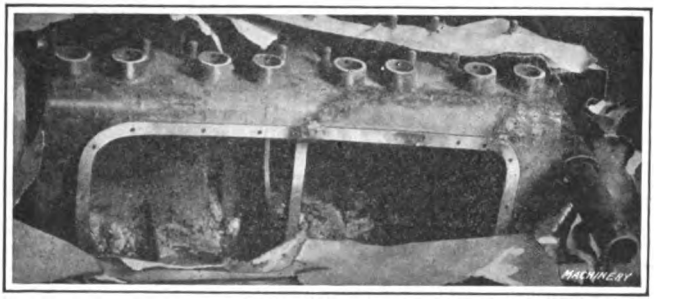



**Fig. 14. Weld Completed**

The work had not been preheated or prepared. The photograph was taken after the break at *C* was partly prepared at the author's shop. The essential thing in this piece was to make the edges of the slots *D*, which form a fork at the end of the casting, come at right angles to the surfaces *E* and *F*, and also to have these two surfaces in line. It was necessary also to be sure that the surfaces *H* and *I* were parallel, as a sliding block operates between them. The method of doing this was to clamp the piece

on the corner of the welding table, as shown in Fig. 16. In order to remove the chill from the casting to some extent, a Bunsen burner as shown at *A* was directed against the break at *B*. The upper half of the weld was made, the casting turned over and blocked up carefully, and the weld finished. It was then tested to see that everything was straight and square. It was found to be in good shape, but if it had not been, the difficulty would have

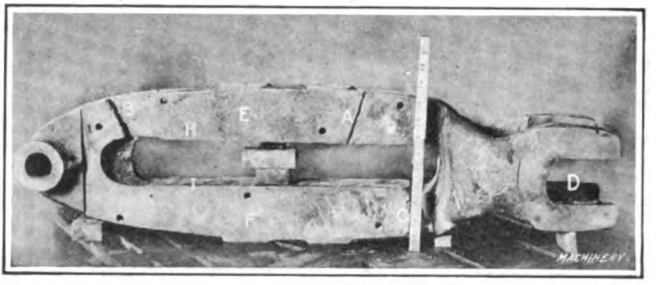



**Fig. 15. Shaper Rocker Arm broken in Three Places. This Arm had been improperly welded and broke again**

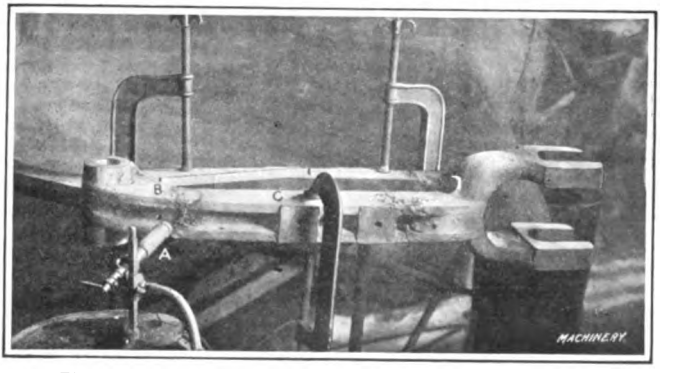



**Fig. 16. Method of Holding Rocker Arm while Welding**

been corrected by heating the weld *B* with a large torch, when the piece *C* could be carefully pulled into position by means of wedges and clamps. The weld was allowed to cool and the piece blocked up on the table as shown in Fig. 17, all the surfaces on the lower side being laid on V-blocks of the same height. The fork-end was then clamped into position so that the slots were true with a square both ways and the top half of the weld *E* made.

It should be noticed that there was enough of the finished surfaces underneath *B* and *C* to allow a narrow V-block to be set underneath which held it true in one plane, while blocking was put under the fork to hold it true in the other direction. Of course, the piece was clamped down to the table, while the first part of weld *E* was being made. It was then turned over and the weld finished, and the piece again tested to see that it was in

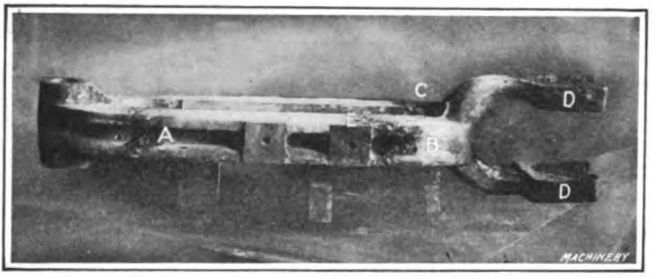



**Fig. 17. Blocking used to insure Proper Alignment of Welded Parts while making Final Weld**

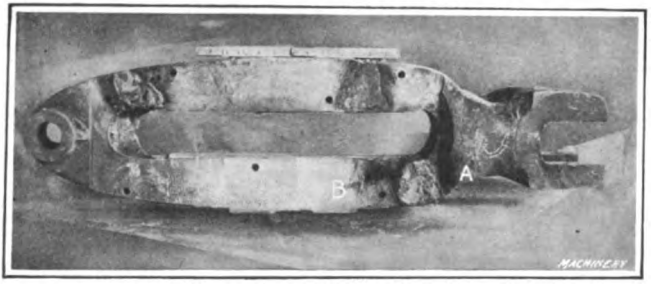



**Fig. 18. Completed Rocker Arm properly welded**

good condition. It is evident that after these operations the piece was true and in line, and, with reasonable care, would remain so. There was, however, danger of a strain in making the last weld. This was overcome by putting tram-marks at *A* and *B*, Fig. 18, and heating the opposite side in a charcoal fire sufficiently to give the necessary expansion, which was checked by the tram-marks. The piece was carefully blocked up so that no sagging would take place, and half the weld made. It was then turned over and the weld finished, the piece removed from

the fire and allowed to cool down in asbestos. The conditions required that all of these welds be made without heating the piece red-hot, because it would have been very difficult to keep the parts in line, had the whole piece been put in a hot fire.

One difficulty in this case was that all of the faces were more or less worn, and some judgment had to be used in checking them up. However, the piece after finishing gave entire satisfaction. The use of small torches or gas burners in this or similar cases is of great assistance, because while they do not bring the piece to a red heat, yet enough of the chill is taken from the metal to save a considerable amount of welding gases, and this also helps to make a better weld. It is evident that it would be quite difficult, if not impossible, to block up such a piece on the table and build up a charcoal fire under it, the heat being likely to warp or crack the table.

**Oxy-acetylene Welding as a Means of Repairing Cylinders.** — Breakages in automobile cylinders can be divided into three main classes which cover at least ninety per cent of the cases. The majority of these breakages can be satisfactorily repaired by means of the oxy-acetylene flame, the cylinder being as good as new. Additional metal is added where necessary from a rod of the same material, and the process consists in practically recasting the part locally. Oxy-acetylene welding is proving a great boon to those who are unfortunate enough to have their automobile cylinders broken, as they can be satisfactorily welded, and in the majority of cases, with a little trimming off, the repairs will not show. Cylinders with cracks were formerly sometimes brazed, but owing to the necessity of heating the whole cylinder to a good red heat to even up the contraction strains, so as not to crack when cooling, the bore of the cylinder was generally warped, and the job required a lot of finishing, as the spelter and flux spread considerably and were difficult to remove. Also, owing to the dirt and rust in the crack, it was difficult to get the brazing below the surface; the high temperature necessary would sometimes crack the cylinder elsewhere.

**Water Jackets Broken by Freezing.** — In the early days of the automobile, the largest class of cylinder breakages — mainly

due to carelessness — was caused by allowing the water jacket to freeze, resulting in the breaking of the water-jacket wall. Also, it frequently happened that when shipping a car by rail in winter the drain cocks were opened, but due to some pocket in the water system (in some cases very small ones) which did not drain, the cylinders broke from the freezing of the water. The cause was really to be found in the faulty design of the water cooling system, and troubles of this kind are seldom or never met with nowadays. The cylinders *A* and *B*, Fig. 19,

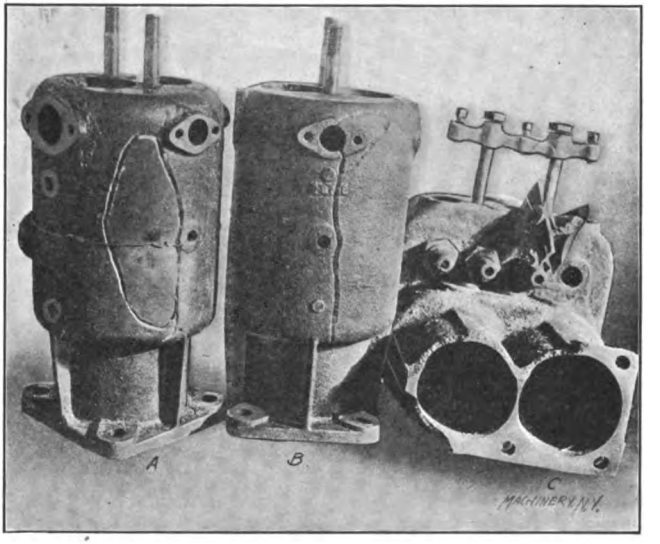



**Fig. 19. Two Cylinders with Cracked Water Jackets prepared for Welding. Twin Cylinders with Broken Flanges to be Welded**

show common types of breakages which were satisfactorily welded every day, a few years ago. The crack in *A* is 17 inches in length.

**Cylinder Wall Broken.** — Another class of breakages is that in which the wall of the cylinder, combustion or valve chamber, is broken or cracked. This class of breakages is difficult to repair, as it is necessary in most cases to cut out a section of the water jacket to be able to work on the inner wall, the only exception occurring when the break happens to be opposite a large hand-

hole. As it often is impossible to determine the length or exact locality of the cracks before cutting away the jacket, and, as it is desirable to remove as small a section as possible, it often is found necessary to cut out additional pieces, thus necessitating welding a number of small pieces back in place when finishing the job. To restore these pieces sometimes is impracticable, and a sheet steel substitute has sometimes been used; this is hammered out and welded in place. With care, this piece can be shaped so as to coincide with the piece removed, and cannot

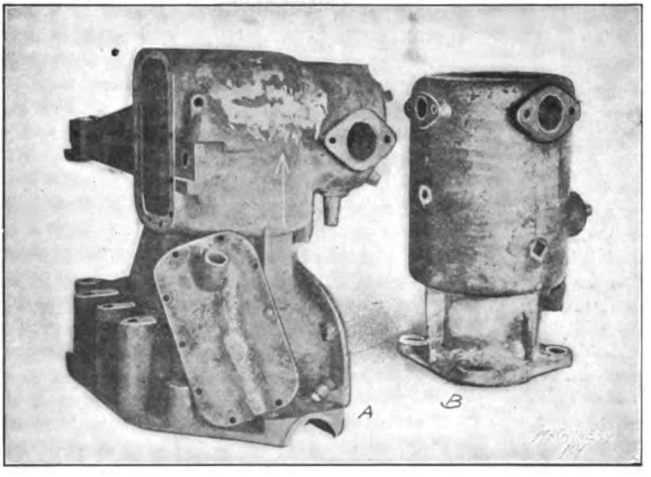



**Fig. 20. Cylinder A repaired by inserting a Steel Piece, bent to Shape, and Autogenously Welded in Place. Cylinder B has had Flange repaired**

be detected when welded in place. The part cut away was thus neatly replaced by sheet steel, as shown at *A*, Fig. 20. It is better, and generally easier, however, to build up the jacket solid, when the original pieces cannot be used.

The cover plate on the cylinder shown in Fig. 20 was also broken at the same time as the cylinder wall was broken, and is shown welded. Fig. 21 shows a cylinder having a crack 8 inches long, located at the corner of the combustion head, that was welded. The part cut out of the water jacket is also shown. It will be noticed that this operation required cutting through a supporting lug.

**Broken Flanges.** — Other common breakages are those in which all, or a portion of the flange, which holds the cylinder to the crankcase is broken away, due either to insufficient metal to withstand the strain or to carelessness in assembling. These breakages occur in two ways; the wall of the cylinder may be broken away or part of the flange may be cracked off. In the latter case, it is an easy matter to make the repair, but, when the break runs through into the bore of the cylinder, considerable care is required. First it is necessary to consider whether it is desirable to weld in the bore, which would then require machin-

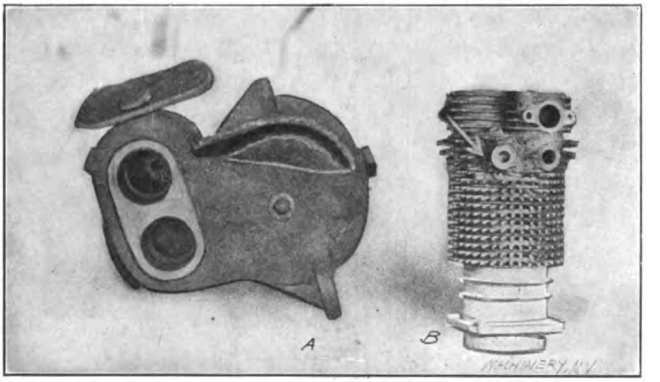



**Fig. 21. Cylinder Cracked in Inner Wall, showing Large Section of Outer Wall removed to Weld the Crack by the Oxy-acetylene Torch**

**Fig. 22. Air-cooled Cylinder on which Boss for Ignition Plug was Autogenously welded**

ing or at any rate filing out, or only groove and weld from the outside to within $\frac{1}{16}$ inch of the bore, sufficient metal being added to the outside to insure strength. The latter method, of course, leaves the crack on the inside, which can, however, be smoothed down and is not objectionable for a repair job, as it does not interfere with the satisfactory operation of the motor in any way; but a more serious objection is that such a repair weld frequently breaks again, and the author has abandoned the practice, and for years has welded all such parts inside as well as outside.

In addition, there is a large variety of other breakages, no two of which are alike, that can be repaired successfully by the oxy-acetylene torch. Considerable welding can also be carried out

by the manufacturer, such as the welding on of additional bosses for dual ignition systems, as shown in Fig. 22, building up bosses that did not "fill" in castings, etc.

**Repairing a Broken Cylinder Casting.** — Fig. 23 shows what frequently happens when some part of the connecting-rod in a motor gives away. This damage is generally the result of not keeping the rods tightened up as they should be. The case

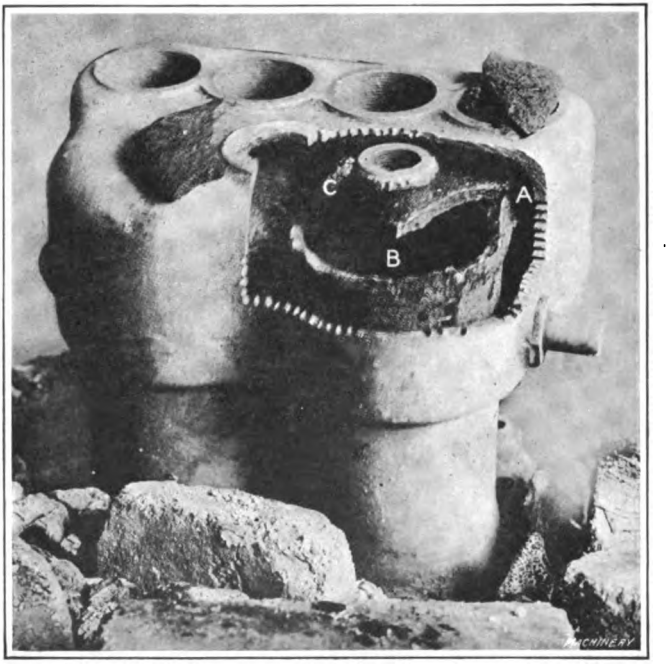



**Fig. 23. Automobile Cylinder with Dome broken and Jacket cut away in Order to Reach Broken Portions**

illustrated is not nearly as bad as some instances, but great care must be exercised in following the crack to the end. If the crack extends entirely through a piece, it will prevent the heat of the torch, when applied to one side, from passing to the other, with the result that where the piece is heated it will become red, while the other side will stay black; but if the crack extends only partly through, as is frequently the case, this test is valueless, and the only thing to do is to melt the iron in the direction in which the

crack extends and pull it out with the welding-rod. If there is a crack, it will show up as a white streak in the center of the melted portion. Therefore, in all cases of this character, and in the case of jacket cracks, the weld should be made entirely through the piece at least 1 inch farther than the crack shows on the surface, in order to be sure that the end is reached. In the present instance the crack at corner *A* extended $\frac{3}{4}$ inch beyond

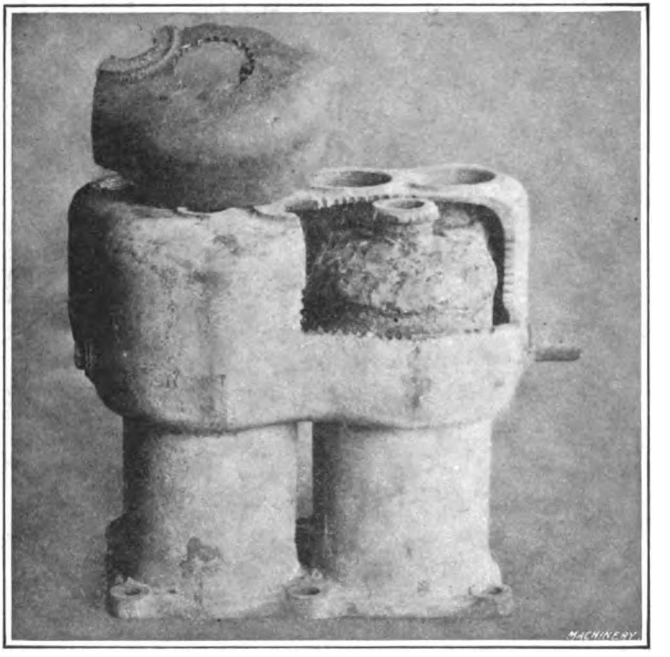


**Fig. 24. Automobile Cylinder shown in Fig. 23 after Dome has been welded**

where it was visible. The pieces were not prepared, nor is it the practice in the author's shops to V the pieces in such cases.

**Preheating of Cylinder.** — Cylinders should always be heated slowly, and the base of the cylinder kept somewhat away from the fire, which should not be too heavy at the beginning. The cylinder should be tilted at an angle so that the heat will pass up through the bore and around the outside, underneath the asbestos paper with which it is covered. After the work is thoroughly warmed through, the defective part should be placed

in the fire so as to become more thoroughly heated than the remainder. At this stage the heating should be watched carefully, and when it has arrived at the proper point, while the temperature is still rising, it should be welded in the fire. Under no circumstances must a cylinder be removed from the fire while the weld is being made, and sufficient asbestos paper should

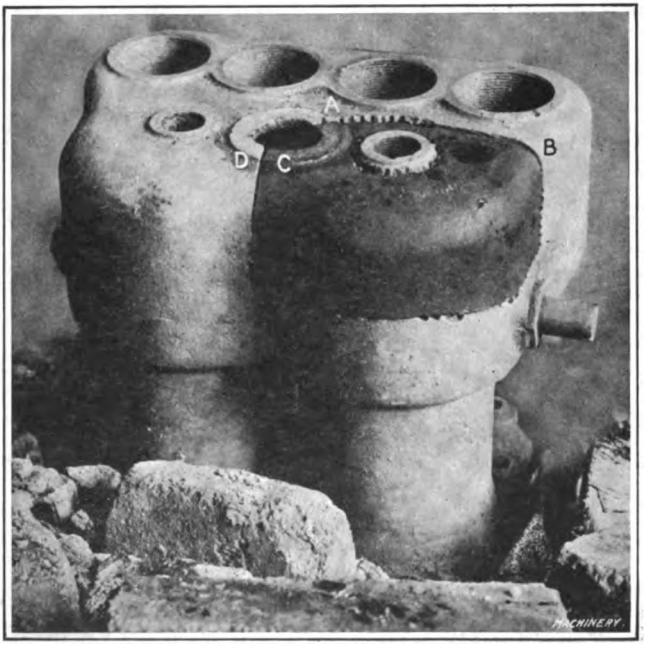



**Fig. 25. Cylinder shown in Fig. 23 with Piece of Jacket set in Place ready for Welding**

be properly located to cover all the cylinder except the part being worked upon.

It is very difficult to explain how hot to heat a cylinder. If possible to avoid it, the heat should not be great enough to make it red at any point. In certain cases the cylinder must be heated to a red heat, particularly where there is a rigid connection between the barrel and the jacket at several points, or where the cylinders have large flat sides. Frequently the proper temperature can be determined by the paint and filler on the cylinder being turned to a rusty brown powder. This test is only of value

when the cylinder is on a rising temperature. It is evident, if it has been heated to this point and then allowed to cool, that it may not be warm enough to avoid shrinkage cracks, while it may appear so to the eye. The best way to obtain experience is to get some old cylinders and experiment with them. More can be learned in this way in a short time than by pages of description.

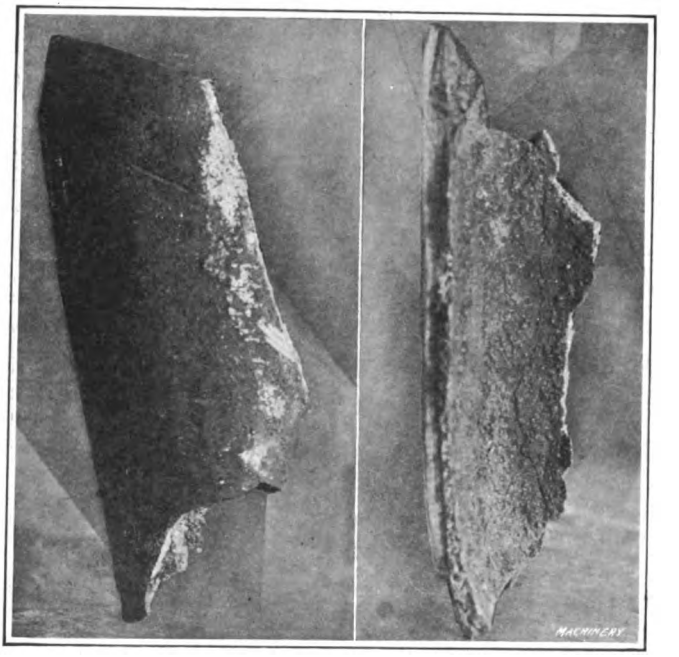


Fig. 26. Cylinder Jacket with Crack not Visible from Outside

Fig. 27. Jacket with Crack Clearly Visible from Inside

**The Welding Operation.** — In this case, as soon as the cylinder arrived at the right temperature, which was higher than for an ordinary jacket crack — very close to a red heat — it was turned into the position shown in Fig. 23, and the pieces welded on. The welding began at *A*, went from there to *B* and *C*, and so on back to the starting point. This gave the maximum chance for contraction to take place without difficulty. The weld was burnt completely through, and, as soon as finished, the cylinder was turned over in the fire and the inside of the weld completed

and smoothed off with a special torch. This is necessary in order to prevent preignition in operation due to small points projecting into the cylinder becoming red hot, or to carbon collecting on such points and causing the same trouble. It is sometimes necessary to have more than one special torch to reach all the corners. Occasionally a cylinder broken in the dome is split part way down the barrel. The only satisfactory way of repair-

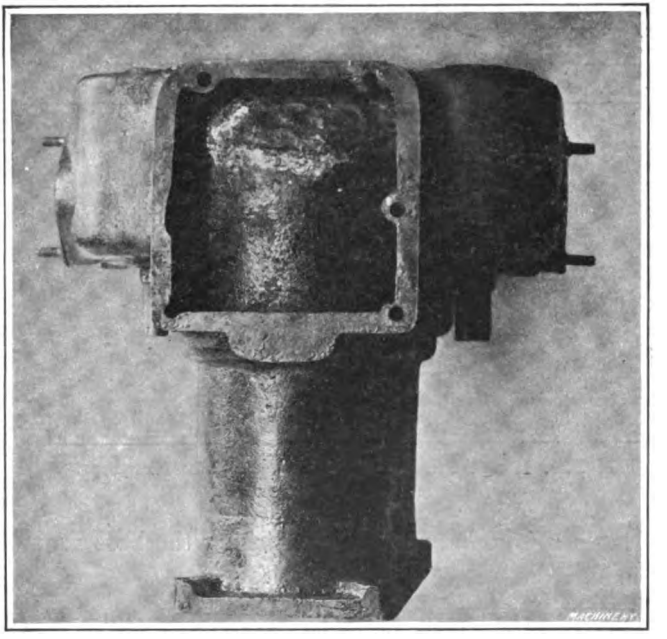


**Fig. 28. Improperly Welded Cylinder**

ing such a crack is to weld from both sides, and then re-grind the cylinder.

After the dome was welded, the cylinder was packed away in powdered asbestos until cold; the proper openings were then plugged and the cylinder tested for leaks. This is always a proper precaution, because while, if the work is properly done, there is little chance for trouble, yet, if there is any difficulty or if any crack is overlooked, it can be welded much more easily than if the jacket is welded right away. However, when time is

an object, as it occasionally is, and if the welder is sure that he has welded the dome properly, the jacket may be welded at once, the whole cylinder packed in asbestos and allowed to cool.

After the cylinder was tested and everything found satisfactory, it was reheated, the jacket put in place as shown in Fig. 25 and welded, beginning at *A* and going to *B*, after which it was welded around the boss, again started at *B*, and continued around to *C*. This took care of the contraction better than any other method. The surface *C* was set, before starting to weld,

**Fig. 29. Rough Condition of Inside of Dome of Improperly Welded Cylinder**

a little higher than *D* to allow of finishing the boss around the center-hole.

Mention has been made of the possibility of a crack extending on the inside of a piece where it is not visible on the outside. A good illustration of this is shown in Figs. 26 and 27, which show a piece broken out of an automobile cylinder jacket in order to weld the dome. In Fig. 26, a crack was visible at the top and bottom of the piece as a very fine line, but it was not visible for more than $\frac{3}{8}$ inch in either case on the outside of the piece. However, it will be noticed that it extends along and is quite clearly visible inside in Fig. 27. This condition may exist not only in cylinder jackets, but in many other pieces, both large and small, and the illustrations are shown to emphasize the necessity of following the crack all the way to the end.

**Defective Welding of Cylinders.** — As an illustration of what results from improper welding of cylinders, Figs. 28 to 30 are shown. The original damage to this cylinder is indicated in Fig. 28, and consisted of a crack in the dome. From the appearance of the inside of the cylinder shown in Fig. 29, the dome appears to be broken in a number of pieces. It does not appear on examination of the cylinder whether the jacket was cut out in order to reach the broken dome, or whether it was broken out originally by the damage. However, in attempting to put it back, the cracks kept on extending until the cylinder was cracked

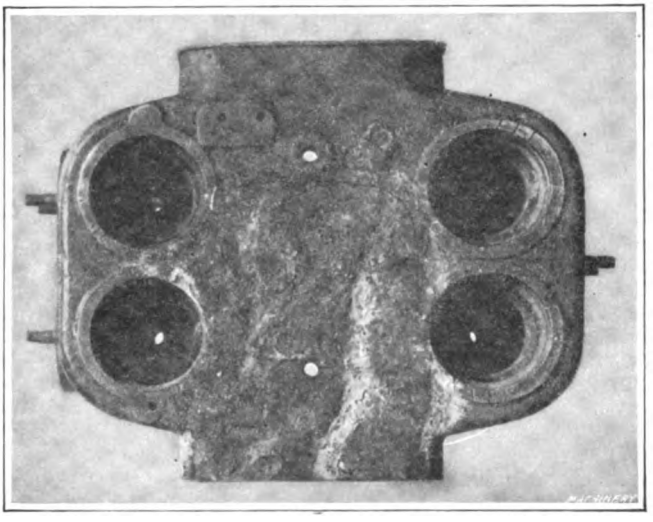


**Fig. 30. Contraction Cracks in an Improperly Welded Cylinder**

through two port plug holes. In addition to this, the corner of the cylinder as welded was much flatter than it should be, the result being that it would have been impossible to grind out the cylinder without going through the weld. In addition to the above, there was no attempt made to smooth off the inside of the dome, with the result that the cylinder would have knocked, on account of preignition due to the roughness. The cylinder as it stands is not beyond repair, if handled properly, but the owner purchased a new cylinder, believing that it could not be fixed.

This is a good instance of the damage to the reputation of the oxy-acetylene welding process caused by those who do not know how to do the work and who have not the proper facilities. This cylinder was not preheated. The possession of a hammer, chisel, and monkey wrench does not make the owner a machinist; neither does the fact that one has a welding torch and oxygen and acetylene tanks enable him to weld anything that comes along. It should be emphasized that proper apparatus, instructions, and training are necessary for the successful carrying out of work such as that shown.

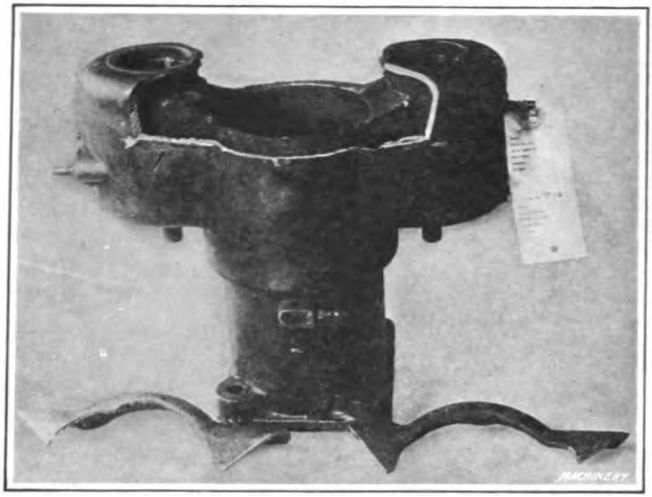


**Fig. 31. Cylinder badly damaged and Jacket cut away to Enable Welding to be done**

**Properly Welded Cylinder.** — As a contrast to the foregoing, Figs. 31 to 34 are shown. Fig. 31 shows the damage to the dome, and the pieces of the jacket cut away to reach it. Fig. 32 shows, on the right, the pieces of the dome, and on the left the pieces of the jacket. In the center is shown the plug going through the top of the dome and jacket. It will be seen that the thread on this is badly damaged. The dome was broken into twelve pieces and the jacket into eight pieces. At *A*, *B*, *C*, and *D* are shown the points where the four ribs extending between the dome and jacket are located, the ribs themselves not being shown.

The pieces are shown laid together on wet asbestos and carefully lined up. They were then "tacked" together with the torch so that they could be used as patterns for castings, the cost of welding all the pieces together being too great; besides, it would be difficult to put the pieces accurately into place. On the castings from these patterns, as shown in Fig. 33, stock was left for finishing, except at the points *A*, *B*, *C*, and *D*, where

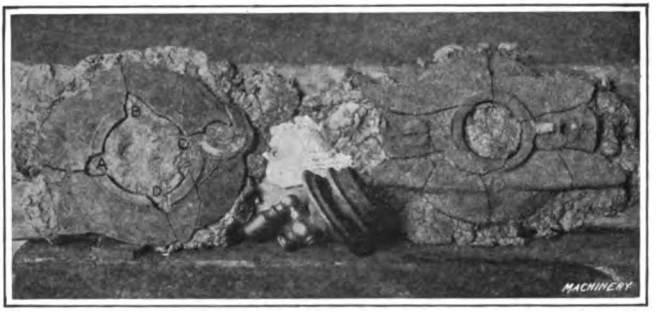



**Fig. 32. Pieces of Broken Dome and Jacket of Cylinder shown in Fig. 31**

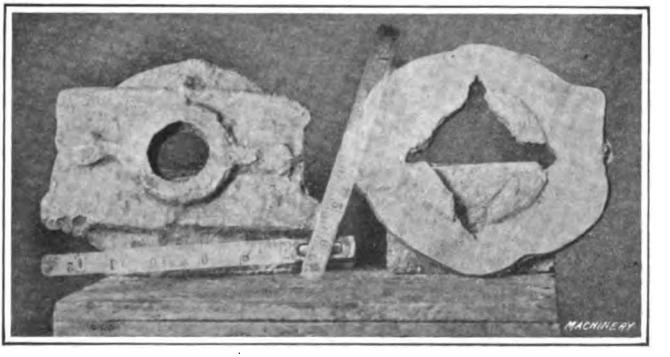



**Fig. 33. Castings used in Making Repairs shown in Figs. 34 and 35**

the connecting ribs between the dome and jacket had to be built up. Fig. 34 shows the dome welded in. Fig. 35 shows the jacket welded in and the dome plug with metal added on the threads. All the machining was done on an ordinary lathe. It was not possible to obtain exactly the same thread on the dome plug as on the original, but this made no difference, as the stock allowed permitted any suitable thread to be used. It was im-

possible in this case to obtain a new cylinder, as the manufacturers had gone out of business; but the cost of repairs was considerably less than the cost of a new cylinder.

Even though there may be no foundry near, the welding of the pieces together and setting them back into place is perfectly possible. They should all be welded together on both sides, the inside of the dome smoothed off by grinding, fitted in place,

**Fig. 34. Dome welded in Place**

**Fig. 35. Jacket welded in Place**

and welded. In such cases, enough of the jacket should be cut away at the beginning to enable the work to be done rapidly, and the planning should be done ahead, so that it will be known exactly how the work is to be handled. There is no necessity of having to plan these things while the work is being done.

**Welding a Heating Boiler Casting.** — Figs. 36 to 40 show a section of a cast-iron heating boiler. Quite a number of these

heater sections break, and as they are expensive, they are well worth welding. The reasons for their breaking generally come under three heads: 1. Allowing the water to become too low in the boiler. This permits the section to become red-hot, and, when it is cooled off, or cold water turned in, a crack results. 2. Casting strains in the pieces. The author has seen new sections not yet installed with bad cracks which could not have

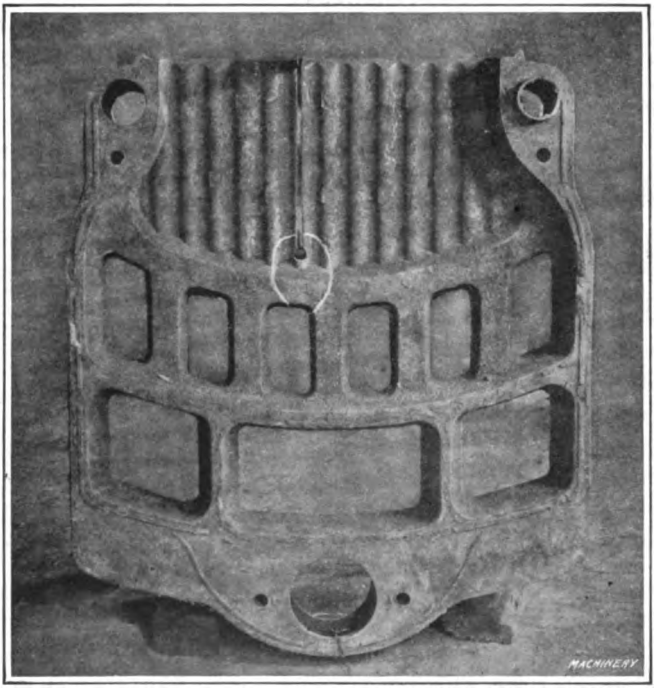



**Fig. 36. Crack in Section of a Cast-iron Heating Boiler**

passed inspection at the foundry. Sometimes, upon inquiry about a cracked section, the statement is made positively that the water was not low, and while this statement may not always be true, yet a sufficient number of cases have come to the author's attention in which he believes the information to have been correct, to warrant the belief that strains in the casting are really a frequent cause of breakage. It is also well known that it is difficult to cast pieces of the shape of these sections without

experiencing casting strains due to the difference in temperature of different parts while cooling off in the sand. 3. Strains are sometimes caused by the holes for the push nipples, which connect the sections, not being bored true, or in line; or, if the sections are not put up correctly, the same trouble may exist. It is also possible to pull the sections together too tightly, and, as the push nipples are tapered and fit in tapered holes, an enormous strain can be set up by too much tightening.

**Difficulties in Welding Heater Sections.** — Cracked heater sections are generally very difficult to weld, particularly if the cracks are in the body of the section. If only a corner is broken off, or if the section has a long leg on each side and the defect is in one of them, the difficulty is materially decreased. Considerable experience is required to make a sound permanent job, and even then satisfactory results may not be obtained at the first trial. The difficulties met with are the trouble of controlling the contraction when cooling, and of preheating correctly, as well as the trouble of turning the section over while hot in order to reach the other side of the weld.

In order to overcome these difficulties, it is necessary, in the first place, to heat the entire section red-hot; this heat must also be uniform. It is believed to be useless to spend time trying to heat such a casting locally, or to provide for contraction by heating one part somewhat more than another. The cause of the crack cannot always be known, and inasmuch as the real cause may be a combination of causes, the only safe way is to eliminate all strains by thoroughly preheating to a high temperature. The contraction while cooling may be overcome by slow cooling obtained by packing the welded casting in asbestos and thoroughly protecting it from drafts. In the case of large sections, this cooling may require forty-eight hours. If the work is to be done outside, in cold weather, great precautions must be taken to insure that the outside edges of the casting do not cool too quickly.

The difficulty of turning over the casting can best be overcome by providing special means for handling. What is done depends upon conditions, and no fixed rule can be laid down;

but the casting must be handled quickly, and if it is turned over, it must be allowed to reach a uniform temperature before the final weld is made. After welding, the casting should again be brought to a uniform temperature, and then carefully packed as outlined.

**Preparation for Welding.** — Fig. 36 shows a section in which the crack was probably caused by an original strain in the casting.

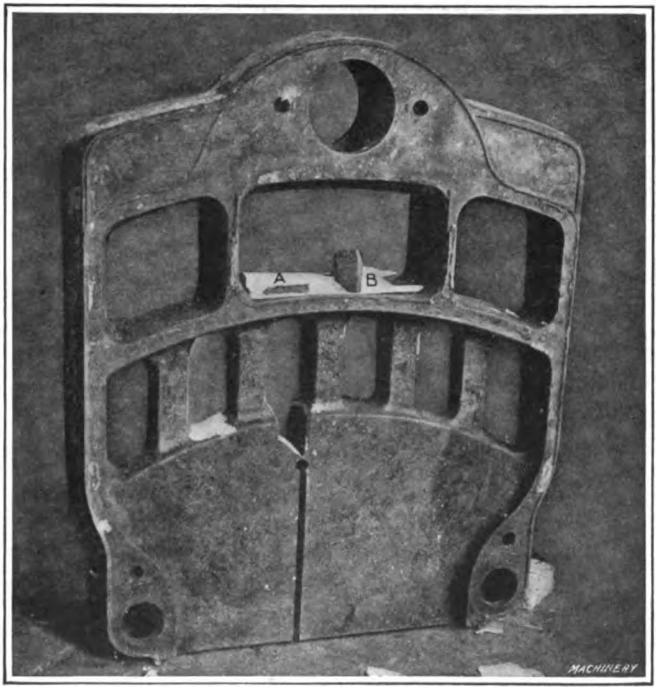



**Fig. 37. Heating Boiler Casting prepared for Welding**

The crack was barely visible, and, in order to show in the photograph, it was necessary to wedge it open somewhat. There was some discussion in the shop as to just how to prepare the crack for welding. It was manifestly impossible to get any torch tip into the hole, which is about 1 inch in diameter, as the section was about 4 inches thick at that point. It was finally decided to prepare the casting as shown in Fig. 37, saving the piece that was cut out (the cutting being done by a hacksaw and

hammer and chisel), so that it could be replaced. The advantage of this method was apparent when the piece was removed, as it was found that there was a boss $1\frac{1}{4}$ inch thick around the 1-inch hole, the piece cut out of the boss being shown in Fig. 37, at *A*, while the main piece removed is seen at *B*. The boss can be seen in Fig. 39, where the section is shown laid on steel plates, blocked up from the concrete floor and with firebricks under

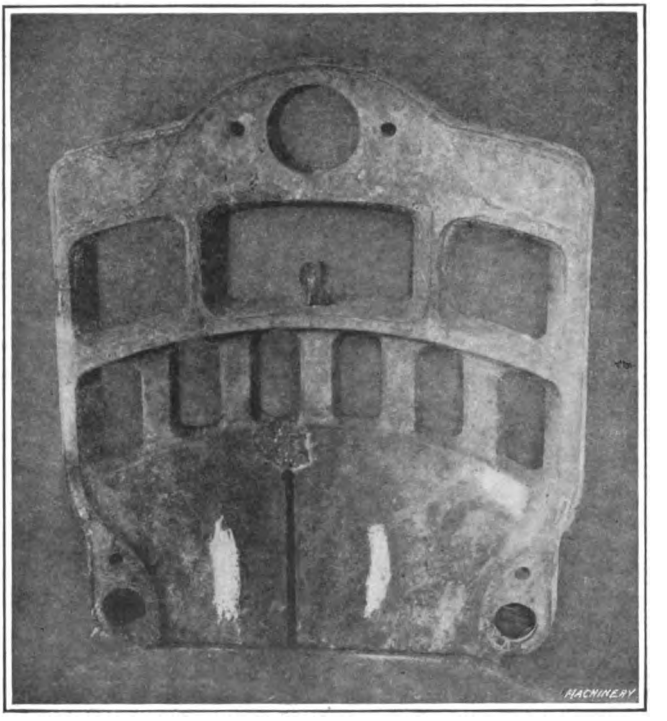



**Fig. 38. Heating Boiler Casting in which Weld is finished**

the corners to leave space for the fire. The tram-marks will also be noticed at *A*, *B*, and *C*, the distance *AC* being equal to *AB*, and being used as a reference length.

**Preheating the Casting.** — Fig. 40 shows the use of old carbide cans cut up into strips of the proper size for confining the fire. These are very satisfactory for the purpose, as they can readily be bent to any shape and are inexpensive. The fire is

applied to such a casting by lighting a considerable quantity of charcoal in a forge and placing it underneath the casting, being sure to distribute it so as to obtain a uniform increase in temperature. This is rather difficult and experience is the only guide.

It is evident that there is more chance for a draft around the outside of the casting than in the center, that a heavier section will require more charcoal than a lighter one, and that in the open spaces too much charcoal should not be applied. In this particular case it was found that too much fire had been put along the part $AB$, Fig. 40, so that, after the casting had become quite warm, the distance between the tram-marks had increased $\frac{3}{8}$ inch. In order to remove the strain set up, the fire was shifted

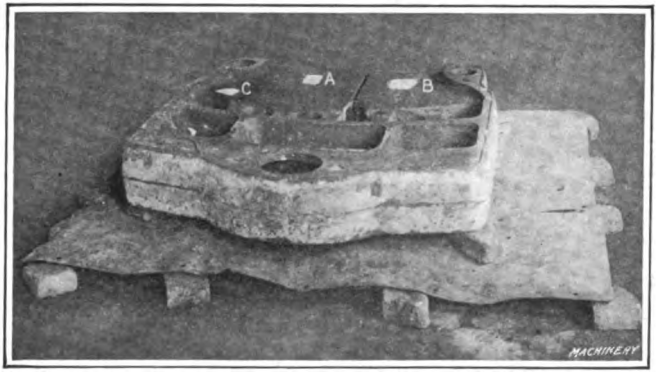



**Fig. 39. Heating Boiler Casting showing Arrangement for Preheating**

toward both ends, but still, after the casting had become red, it was found that after allowing for expansion, the tram-marks had separated $\frac{3}{16}$ inch, which indicated that there was a strain somewhere in the original casting.

When the charcoal was first placed underneath the section, care was taken not to use too much, and from time to time, as the casting became warm, it was added in small quantities, but more rapidly toward the latter part of the heating; during this time, the top of the casting was kept covered with asbestos paper. It is necessary, however, to punch holes in the paper to permit of sufficient draft to keep the charcoal burning. The paper tends to distribute the heat more uniformly.

**The Welding Operations.** — The first welding done was to weld the boss. On account of the difficulty of reaching it, the casting had to be raised from the fire and stood on its end, so that the work could be done quickly. It was carefully covered with asbestos paper while this weld was being made, then replaced in the fire and allowed to come to a uniform temperature. Then the piece which had been cut out was put into place, and the sides *C* and *D*, Fig. 40, welded. The casting was then turned over, again allowed to come to a uniform temperature, and, beginning at what was then the bottom of the welds, the V's were filled up and the weld

**Fig. 40. Heating Boiler Casting ready for Preheating Fire to be started**

finished at the boss. During the welding it was necessary to pack the top of the casting heavily with asbestos, as the welders had to stand over it to reach the bottom of the vertical welds. It always pays to protect the welders as much as possible in case of heavy fires, as, if this is not done, they cannot do good work.

**Distortion of Casting.** — After the weld was finished, it was found that the trammed distance had increased $\frac{1}{8}$ inch. Inasmuch as there was no strain in the casting after the work was done, as it had been uniformly heated after welding, this $\frac{1}{8}$ inch represented the total amount of strain in the casting. When cold, a thorough hammer test with a light sledge was made, as well as a pressure test, and everything was found to be in good

condition. It is evident that this $\frac{1}{8}$-inch expansion had to be taken care of, as the push nipples could not be put back in place if it were not. The following method of taking care of it has been found in all cases to be entirely satisfactory. The push nipples are made either of cast iron or steel, and the method followed is to cut the nipple in half with a hacksaw. The section is erected in place with each half of the push nipple in its

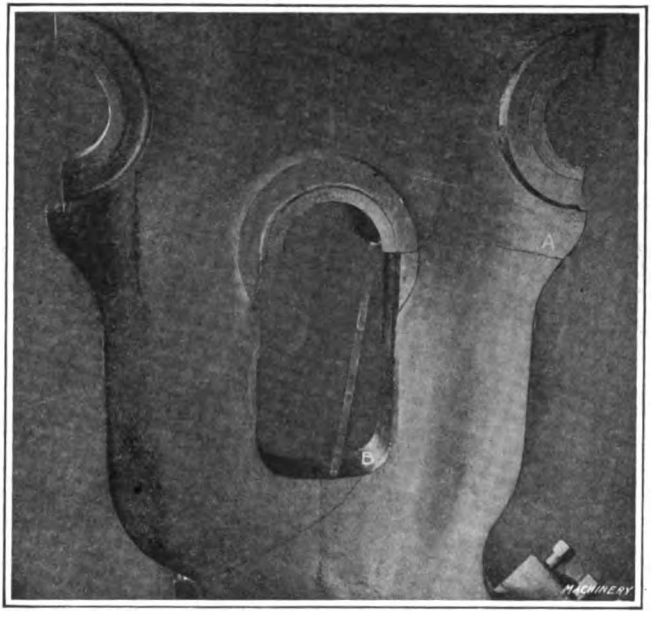



**Fig. 41. Upright of Broken Press Frame**

respective hole. A line is then carefully scribed with a sharp point along the exposed surfaces where the two halves offset, the pieces removed and welded to suit their new position. If this is carefully done, it will be found that the result is entirely satisfactory.

**Repairing a Press Frame.** — Fig. 46 shows a large press frame which is broken. The top of it is very close to the wooden roof of the building. Inasmuch as it would have been quite expensive to remove the casting, an attempt was made to weld it in place. Fig. 41 shows the size and nature of the breaks, the bottom of

one of which was comparatively easy to reach, both to prepare and weld. Fig. 42 shows that the top break was prepared nearly through the casting at the point *A* from the side shown, while at *B* the preparation was made equally on both sides. This was done in order to save the bearing. It will be noticed from Fig. 46 that the bearing on the inside of the broken side had a large projection, and nearly half of this would have had to be cut off if the bevel had been prepared evenly on both sides.

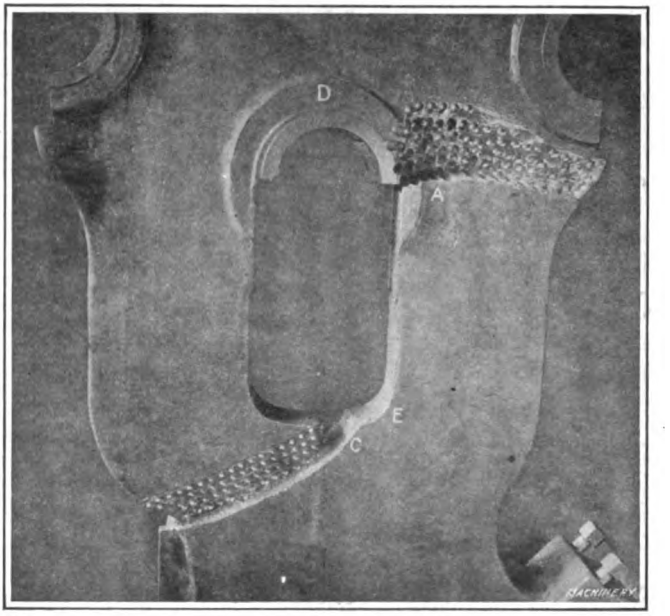



**Fig. 42. Showing Breaks through Metal 5 by 17 and 5 by 14 Inches**

**Preheating and Welding the Frame.** — The heating of these breaks, particularly the upper one, was quite a problem, and trouble was anticipated in controlling the contraction, partly because the upper part of the casting was much heavier than the lower part, and also because, as it was very close to the wooden roof, it was feared that sufficient heat could not be applied to raise the casting to the same temperature as below; that this fear was justified was proved by the results. However, it was determined to make the attempt, a plan having been worked out

whereby, if trouble should occur, it could be overcome. The heating was done by pans made of old carbide cans hung by wire from the upper part of the casting and surrounding the welds. These pans were located in order to secure as uniform an expansion as possible, and, while the breaks shown in Fig. 42 were being welded, fire was maintained in pans on the opposite side in order to avoid any irregular strains due to vertical contraction. It was, however, not anticipated that any trouble

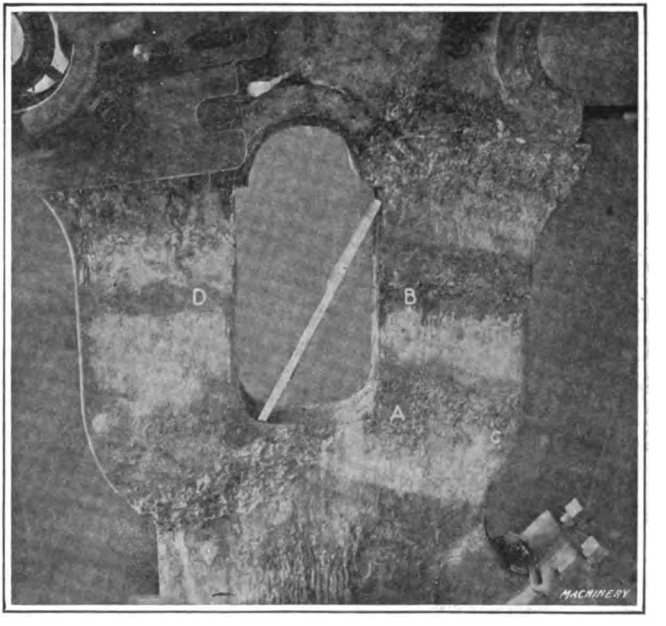



**Fig. 43. Crack on Opposite Upright prepared for Welding**

would come from the vertical contraction. The difficulty feared was the difference between the horizontal contractions at *C* and *D*, Fig. 42. It is evident that section *C* is much lighter than *D* and that, in order to extend the castings the same amount, a much heavier fire would have to be maintained at the latter point than at the former. While the pans were placed entirely across the top at *D*, it was found impossible, with as heavy a fire as could be kept up, to obtain the same amount of expansion horizontally, although the width of the fire was about 4 inches

all around the casting, except at *E*, where the pan was cut off to allow the casting to stay as cool as possible. In other words, the lower pan went no further than the break, while the upper pan not only covered the break but also the opposite side of the casting.

In spite of these precautions, and while no new cracks appeared directly after the welds were made, a hammer test later developed a crack at *A*, Fig. 43. This was the result anticipated.

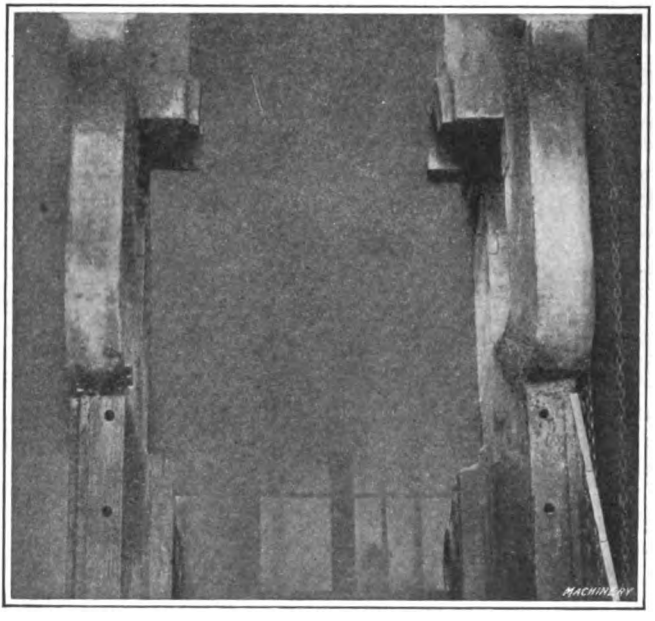


**Fig. 44. Press Frame showing Breaks prepared for Welding by Drilling and Chipping**

The solution of the trouble was to first cut the casting entirely through, as at *B*, and weld *A*. The crack at *A* only extended about 4 inches from the inside corner, but the V was made on both sides about $1\frac{1}{2}$ inch deep at *C*, in order to insure uniform heating with the torch. It was an easy matter to place a pan opposite *B* and one at *D*, and also two others opposite *B* and *D* on the other side of the frame. The desired expansion was obtained without any trouble, and the casting welded at *B;*

the tram-marks showed that the casting came back to its original position.

In Fig. 44 will be seen the preparation of a small crack on the left upright. This gave no trouble in welding, as the large body of metal left forced the expansion to take place as was desired. However, the precaution to heat the other upright also was taken while welding. The whole casting weighs about twelve tons.

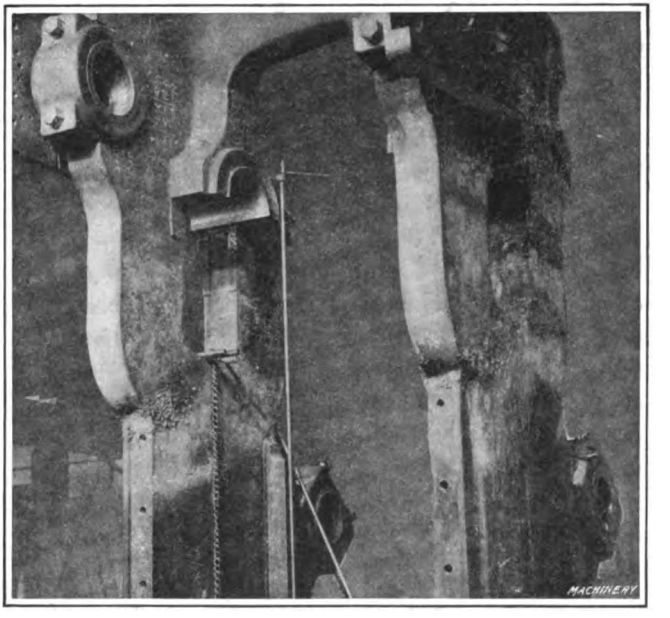



**Fig. 45. Section of Press Frame after Welding**

The problem in this case was to do the welding without removing the frame. There would have been no trouble in welding it had it been removed, because not only could the different parts of the casting be brought to a uniform temperature, but, as the welding would have been done horizontally, it would have been much easier. As it was, all the metal had to be added on the side. The two main breaks required four welders for a period of twenty-two hours, as the heat was very great, due to the low roof, which it was necessary to protect from damage by fire, and also due to the fact that the space between the

uprights was only about three feet, so that part of the time the men were working between the pans on the upright.

There was a shrinkage strain in the original casting; this made it necessary to rebore the bearings. It was realized before the job was started that this would have to be done. This frame has been in service for over a year since welding, and has been subjected to heavier work than ever before, with entirely satisfactory results.

**Difficulties with Cast-iron Welds.** — A difficulty that is encountered in certain cases, particularly in cast iron, is the formation of blow-holes extending from some distance down in the weld to the surface. These are generally small and in the majority of cases not important. However, in gas-engine cylinder water jackets or similar places, where leaks are objectionable, they should be avoided, and in all cases care should be taken to remove them during welding. They are caused by small particles of slag or dirt, which contain in them a certain amount of air or gas. They can generally be noticed by their intensely white color. They are probably composed of silica which will not melt. All that needs to be done is to melt the metal around them and allow them to float to the surface, removing them either with the welding-rod or by the use of scaling powder. A similar condition is sometimes noticed in a piece that has not been heated sufficiently; here the remedy is obvious.

**Hard Spots.** — There is one condition that exists frequently in cast-iron welds which has caused a great deal of trouble and rather adverse comment, and that is "hard spots." If good welding-rods are used, the spots are the result of carelessness in welding, and generally occur at the points where the old and new metal join. It is very easy to avoid them by making the new metal at the edge of the weld a little higher than the surface of the old metal, and then melting the old metal and new metal, allowing the new to run into the old. If this is properly done, there will be no hard spots at that point. It is a mistake to say that scaling powder produces hard spots. Certain kinds may make a very thin hard film on the weld, but the hard spot which gives trouble is the one first referred to. Of course, in some cases

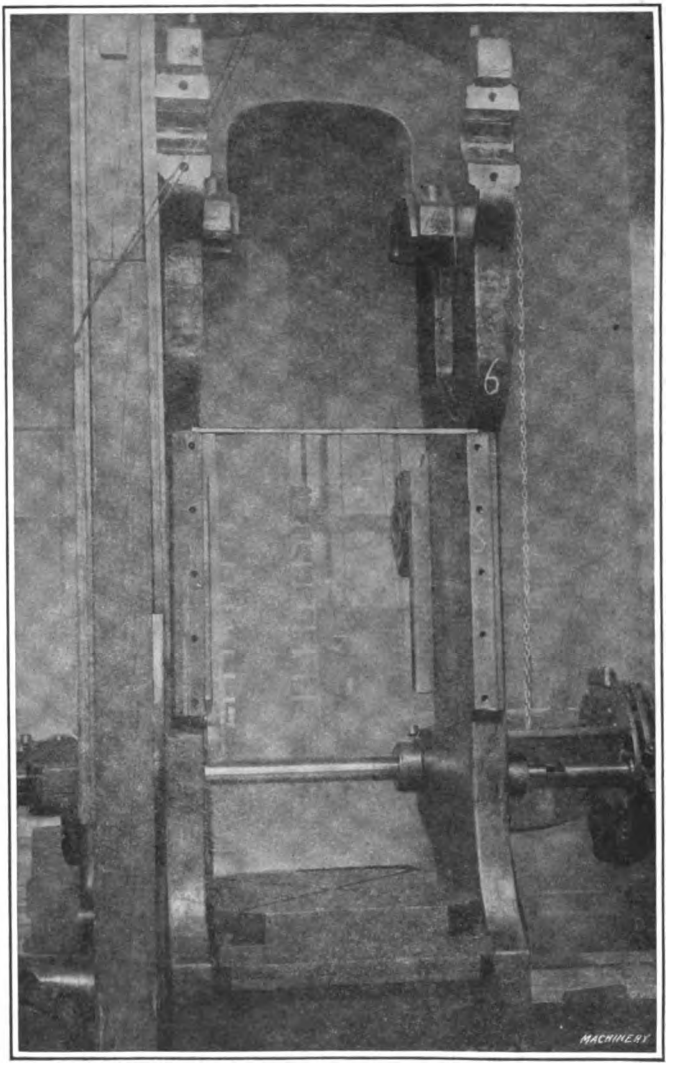



**Fig. 46. View showing Both Sides of Press Frame after welding is completed and Bearings have been repaired**

where no finishing is to be done except by grinding, it is not worth while to bother about hard spots, but where any machining or filing is necessary, they should be avoided. The real cause of such hard spots is as follows:

It will be noticed that they generally occur in comparatively thin sections, or, if in thicker sections, where the metal has not been thoroughly heated; also that they generally are more frequent in fine-grained iron than in coarser metal. The presence of silicon, manganese, and sulphur in iron in certain proportions produces a metal that will readily chill when heated and allowed to cool rapidly. The presence of large amounts of the elements favorable to producing soft iron will not, under extremely rapid cooling, make the iron soft. Now in thin sections, air cooling and the conduction of the heat away by the colder surrounding metal are sufficiently rapid, with the proper chemical composition, to produce chilled iron, and it is surprising how heavy the section may be and still chill when cooled in the air. If allowed to cool in the fire, the cooling will be much slower and there will be less danger of hard spots. The action is really the formation of chilled iron, and from such tests as the author has made, the chilling does not take place in the added metal, but occurs entirely in the original material. This is on account of the high amount of silicon in the welding-rod, which is favorable to the production of soft iron.

Malleable iron, when heated beyond a certain point, will revert to its original state of white or chilled cast iron with consequent hardness. Care should be taken not to heat the metal any more than is absolutely necessary. There is no other metal that gives any trouble from hard spots.

**Chilling Effect of Welding Table.** — Very often the welding is performed on a metal table, in order to facilitate alignment of the broken pieces. If the casting to be welded is a flat section, a very natural thing for the welder to do is to lay it on the welding table and, by simply butting the edges of the break together, alignment is secured and the weld made. No thought is given to the conduction of heat from the weld by the cold table surface, with the result that the heat is carried away from the weld and at least the bottom part of the weld is chilled and made hard. A casting welded under these conditions may be warped. If it is essential for a weld to be made under these conditions, use asbestos paper or firebrick to prevent the conduction of heat;

but, when possible, make the weld in a forge, or use a charcoal fire, a gas torch, or an oil torch, both to preheat and to effect slow cooling. The safe and economical way is to use one of these agencies to bring the line of welding up to the red heat, make the weld, then use the same agency to again bring the work slowly back to a red heat, and cover it with a good nonconductor, such as asbestos, mica, or ashes.

**Distortion in Welding Cylinders.** — Another difficulty that quite frequently arises is the claim made by a customer that the

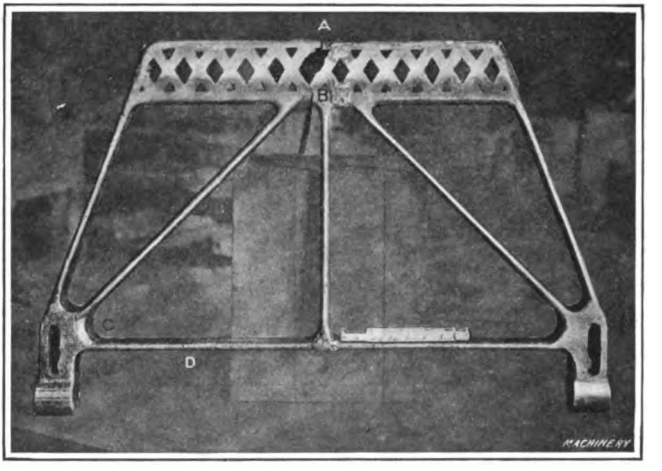



**Fig. 47. Foot-treadle illustrating Difficulties in Welding**

piece has been distorted by welding; for instance, an automobile cylinder in which the bore is claimed to have been warped by heating. This does occur at times, but only in cases of very bad breaks, in the case of a certain type of cylinders where the connections between the cylinder barrel and jacket are so rigid that it requires a red heat to make the weld, or where the cylinder is carelessly overheated. There is also a number of old-style cylinders which were not annealed after rough-boring, and which warp out of shape even with the moderate heat required for jacket welding. The author, in the beginning of his work, measured with a micrometer caliper the diameters at both the top and bottom of a large number of cylinders, and, with the exceptions

above noted, he has yet to find any noticeable distortion of cylinders of automobile motors or gas engines. Of course, there is always some difference in diameters of such cylinders after a period of service, due to natural wear. This is sometimes excessive, and will be readily detected by proper measurements before welding.

The following case, while not of this type of cylinder, illustrates the point very well. A Corliss engine, 16 inches in diameter by 36 inches stroke, burst out the top of the steam chest by freezing, due to the man in charge not draining it during cold weather. The cylinder was calipered at three points and

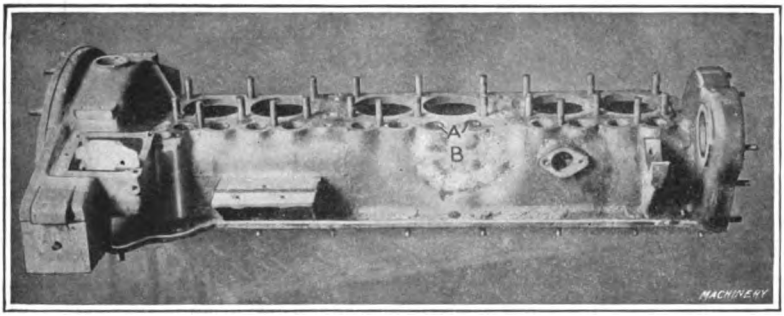



**Fig. 48. Crankcase in which Shrinkage Strains had to be overcome in Welding**

gages made to suit, a maximum difference being found of 0.012 inch, due to wear. After welding and cooling, the latter requiring two days, it was found that the maximum change of dimensions of the bore was less than 0.003 inch, not enough to cause any trouble. The claim of the customer that the cylinder had been distorted was, therefore, readily disproved. It is easy to see, however, that if the precaution of measuring before welding had not been taken, it would have been very difficult, if not impossible, to convince the customer that the welding operation had not injured his cylinder. Therefore, it is advisable, in the case of any job about which a question is likely to be raised, that careful measurements be taken, the accuracy depending upon conditions, and a record kept for future reference.

**Expansion and Contraction.** — One of the greatest difficulties to be contended with is the control of expansion and contraction due to differences in temperature of different parts of the piece welded. Cast iron, being comparatively brittle, is peculiarly subject to cracks caused by temperature strains, but all other metals have also such strains in them, and, while they may not

**Fig. 49. Duplex Pump Base showing Method of Lining up Bearings and Saving Babbitt**

crack, they change their shape, if care is not taken to handle them properly. There is no general rule for taking care of expansion and contraction strains. It must be remembered that they are always present, and experience will show in what way they will manifest themselves. Sometimes they can be avoided by setting the pieces so as to allow the shrinkage to bring the parts to their original shape, but considerable thought and ingenuity

has to be exercised at times to take care of it. Sometimes a sound weld can be made, but the strains will have been distributed through the piece, distorting it and requiring the addition of extra metal to some of the finished surfaces so that they may be machined to their original dimensions.

**Practical Examples of Neutralizing Contraction Stresses.** — Fig. 47 is introduced to show the principle of taking care of

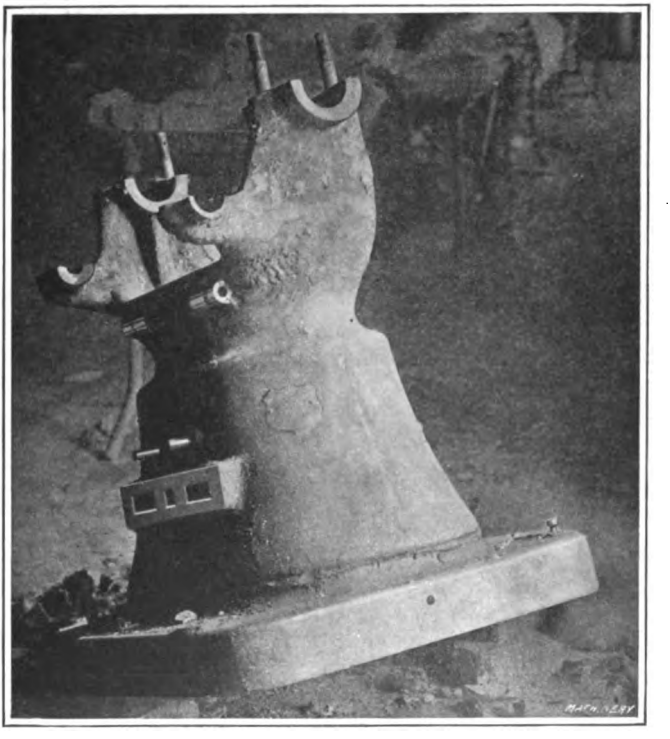


**Fig. 50. Duplex Pump Base showing Finished Weld**

contraction. It will be noticed that this piece has been welded before and that it did not break in the weld. It really is not strong enough for the work to which it is subjected. Before taking the photograph, the crack was wedged apart to show it more distinctly. If breaks *A* and *B* are welded at different times, it will be hard to avoid shrinkage strains, as the distance

between the two welds is very short, not over 3 inches. If, however, they can be welded at the same time, this difficulty will be overcome, as the shrinkage will be uniform. If the crack is opened to allow for contraction, the edges of the crack will not separate parallel to each other, but will swing around the

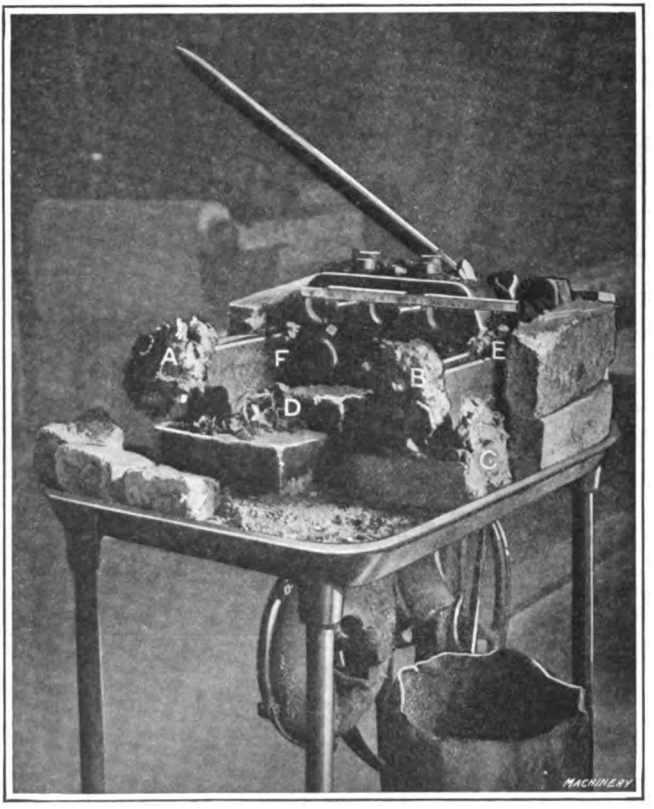



**Fig. 51. Pump Body showing Method of Saving Babbitted Bearings**

point *C* as a center, causing strain at that point. The method followed, therefore, was to heat the bar *D* with a gas flame sufficiently to open the crack the desired amount. Two welders, one working on each crack, finished the welds at the same time. A heavier tip was used on crack *B* than on crack *A*, as the section was heavier and larger. It might be stated that the old welds

shown were made over a year before the piece broke the second time.

Fig. 48 is shown to indicate one method of partly overcoming shrinkage strains that would ordinarily occur. The break does not extend to the bottom flange of the crankcase. The part broken out was in four small pieces when received, and, in welding them in, the edges were welded first, leaving the section *B* about $\frac{1}{16}$ inch higher than its original location. Before welding, a little metal was added to the edges of the holes *A* in the

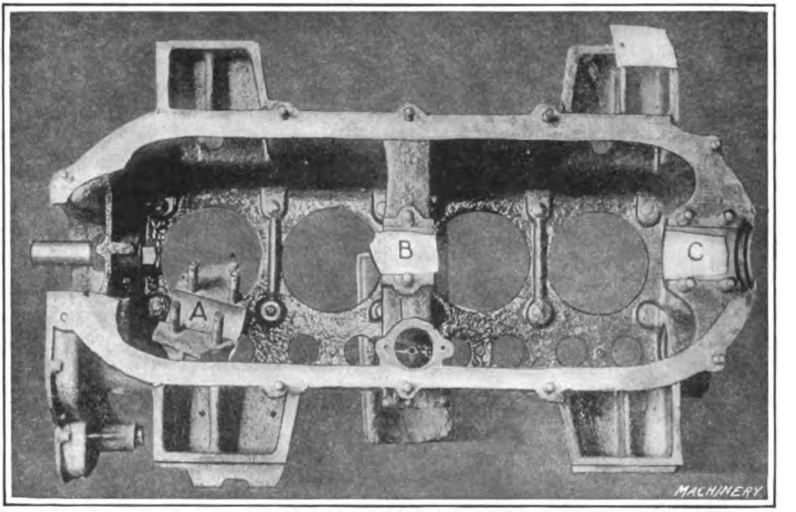



**Fig. 52. Crankcase in which End Bearing is broken off**

piece, to provide for the elevation above described, so that the holes could be finished to their original size. The bridge between the holes was welded first, then the sides, and after that the center. While this will not entirely remove the shrinkage strains, it gives a certain opportunity for shrinkage to occur without causing trouble. In this instance, the metal was of good quality and no trouble whatever was experienced. This method can also be followed at times in welding badly frozen cylinder water jackets.

**Saving Babbitt Bearings when Welding.** — A method used for saving the babbitt bearings, and also for the purpose of lining up the bearing that was broken off as shown in Fig. 50, is indicated

in Fig. 49. A piece of 3-inch seamless tubing was clamped in the bottom bearing, using a piece of asbestos paper *E* to raise it slightly above its original position to allow for shrinkage. Additional allowance was made by raising the bearing *A* about $\frac{1}{32}$ inch vertically above the proper position. The bottom of the tube was plugged with wet asbestos, and it was then filled with water. Asbestos, as shown at *D*, was packed around the bearing and the fire built as usual, the sheet of tin *H* being placed to locate the bottom of the fire. The bricks below the

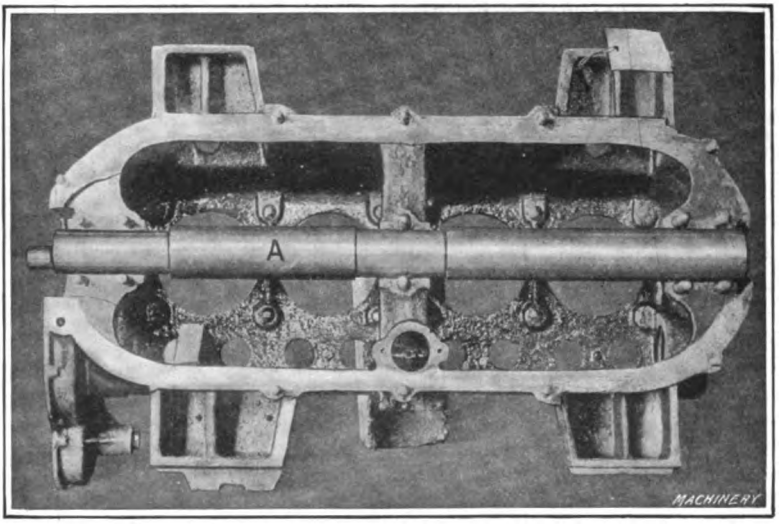



**Fig. 53. Same Crankcase as shown in Fig. 52 with End Bearing and Mandrel in Place**

tin are simply for the purpose of supporting the fire. The bricks above the tin surround the fire and confine it to the desired location. The break was at *C* and is more clearly shown in Fig. 50 which shows the finished job. The metal was $1\frac{1}{2}$ inch thick and the break 12 inches long. When tested after cooling, it was found that the bearing was in alignment within the thickness of a piece of paper, or about 0.003 inch. A slight scraping was all that was necessary to take care of this.

Fig. 51 shows one method of preserving babbitt bearings in cases where the part is to be heated to a high temperature. The

break in this case was on the bottom of the pump body. It is evident that this had to be heated quite hot in order to compensate for shrinkage. This was done in a furnace built of firebrick, the bearings being covered at *A*, *B*, *C*, and *D* with wet

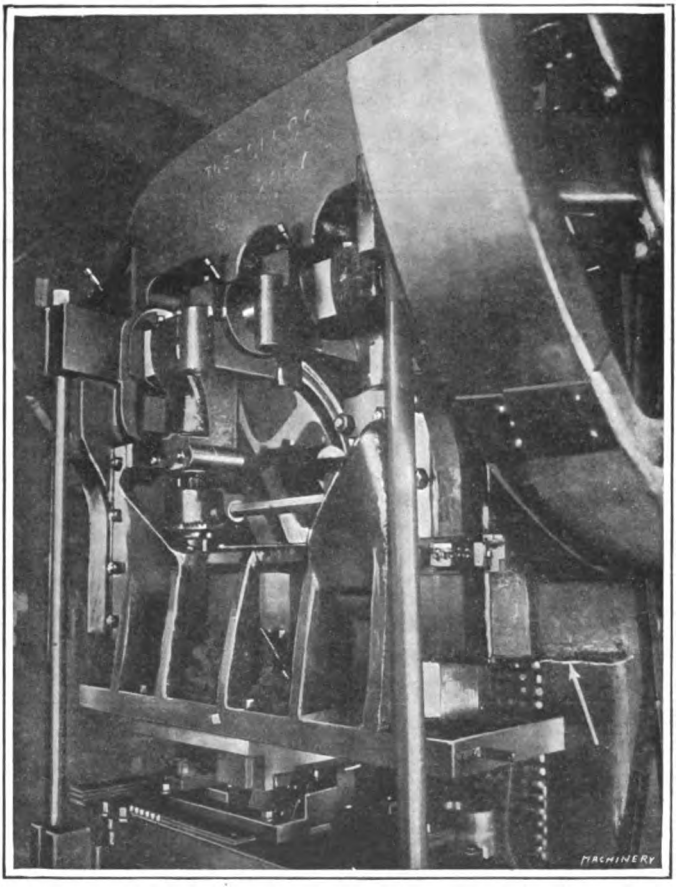



**Fig. 54. Eighty-five-ton Press, showing where Crack was repaired in Main Frame**

asbestos, and the channels at *E* and *F* plugged with asbestos to keep the water in them from running back into the fire. These precautions, together with keeping the asbestos constantly wet and the channels filled with water, answered the purpose admirably and the bearings were not damaged.

**Providing for Proper Alignment.** — Figs. 52 and 53 show a method that can be frequently employed to replace a bearing so that it is very nearly, if not absolutely, in its original position. In Fig. 52 two pieces of cardboard, each about 0.015 inch thick, have been placed in the two sound bearings. The broken-out end bearing *A* is then put in place without the use of any cardboard, a mandrel being held in bearings *A* and *C*. Bearing *A* is held against the mandrel by means of clamps and the nuts of the bearing cap studs. This raises the bearing *A* slightly above its original position, and compensates for the shrinkage of the weld, and in this particular case no finishing was needed except a little scraping of bearing *A*. The three bearings in this instance are of different sizes. It should also be stated that cold-rolled steel, while it is quite heavy, is, as a general rule, cheaper for mandrels than tubing. Of course, if many crankcases of one kind are to be taken care of, it will be better to use tubing, but this material is expensive and, for ordinary purposes, unnecessary.

**Punch Press Repair.** — Fig. 54 shows a repair made in a large punch press, the capacity of which is eighty-five tons. This press developed a crack in the main frame shortly after it was purchased, as indicated by the white line in the illustration. A new frame would have cost about $700. It was repaired by the oxy-acetylene welding process for approximately $150. In repairing, it was necessary to dismantle the entire machine, lay it on its side, and cut away most of the frame at an angle of approximately 45 degrees in the crack. The part was heated by two blow torches to a bright red. Then the process of building it up with the oxy-acetylene flame proceeded, the time required being about twenty hours of continuous work. After the job had cooled, the press was put back on its foundation and the main shaft, which passes through four solid bearings in the main frame, was found to fit perfectly. Every part went back into place without the slightest indication of binding. The frame of this press is stronger to-day than a new one would have been, because the weak part is built up and is thus reinforced.

## CHAPTER VI

### WELDING STEEL, MALLEABLE IRON, COPPER, AND COPPER ALLOYS

THE melting point of ordinary machine steel is about 2650 degrees F., that of wrought iron about 2740 degrees F., while that of cast iron varies, depending upon the composition, from 2000 to 2200 degrees F. Hence, the welding of wrought iron and steel presents a problem entirely different from that involved in the welding of cast iron. Steel less than $\frac{1}{8}$ inch thick can be welded without the addition of any metal. If the thickness exceeds $\frac{1}{8}$ inch, the edges should be beveled or chamfered. It is very important not to add any welding material until the edges are fused or molten at the place where the weld is being made. The welding metal should be of special wire, and in no case should the flame be held at one point until a foam is produced, as this is an indication that the metal is being burned.

**General Procedure in Steel Welding.** — The flame should not be held steadily in the center of the weld, but should be given a circular motion with an uplifting movement at each revolution, the object being to drive the molten metal toward the center of the weld. An excess either of oxygen or acetylene is dangerous in welding steel, and care should be taken to keep the flame neutral at all times.

**Metallurgy of Iron and Its Relation to Welding.** — Iron is one of the chemical elements, existing in large quantities in nature in the form of ores. These ores are reduced by various processes and from them is produced, first, pig iron. In the production of ordinary castings, the pig iron is remelted and mixed with scrap castings and other materials, to produce what the foundryman desires. The metal, however, retains all the characteristics of pig iron, except that its constituents vary in quantity. All cast iron consists of pure iron mixed with different

proportions of carbon, silicon, manganese, sulphur, and phosphorus. There are other elements, but they exist in such small amounts and have such a slight effect on the quality of the metal that they need not be considered here. The effect of these five elements on the quality of cast iron depends upon their relative proportions; and while much is known in this connection, there is still much to learn, as their influences are complicated, not only by their effects on the iron, but upon each other. The element that has, by far, the greatest effect on iron, is carbon; in fact, it has more effect than all the others together; and as the others are present in comparatively small amounts in good iron or steel, they will be considered only incidentally.

**Influence of Carbon.** — Carbon exists in pig iron, or ordinary cast iron, in two conditions, which are called "combined" carbon, and "free" or "graphitic" carbon. The combined carbon exists as carbide of iron, or, in other words, it is alloyed with the iron, forming a definite chemical compound. Graphitic carbon exists in the free state as graphite, and can be noticed in very soft pig iron as it will blacken the fingers or make a mark on white paper. Cast iron contains a total amount of carbon varying from about $2\frac{1}{2}$ to $4\frac{1}{2}$ per cent. The percentage of graphitic carbon in a cast iron having a given total amount of carbon, varies in accordance with the size of the casting and the rapidity with which it is cooled. Slow cooling of a large casting increases the percentage of graphitic carbon, while the total amount of carbon remains the same. This graphitic carbon exists in the iron in the shape of plates between the grains, and it is evident that the larger these plates are, the weaker the iron. It is well known that large castings have less tensile strength per square inch than small castings poured from the same ladle.

**White Iron.** — There is a variety of cast iron known as "white" iron which contains no graphitic carbon. It is sometimes called "chilled" iron, because when iron of proper chemical composition is cast against a steel or iron chill plate, or other cold surface, it cools quickly and the quality of intense hardness which is desirable in certain castings is obtained. It is called white iron on account of its silvery appearance when broken.

Iron suitable for chilling has a smaller percentage of silicon and a larger percentage of manganese than ordinary cast iron, because silicon has the property of preventing carbon from combining with iron, while manganese has exactly the opposite effect. This is the reason why ordinary cast iron is unsuitable for welding-rods. Ordinary castings do not require a high percentage of silicon, and a reasonable amount of manganese is not objectionable, but is of some advantage at times in making the iron close-grained and strong and in counteracting the bad effects of sulphur. Therefore, welding-rods are made from iron which is high in silicon and low in manganese, so that the metal in the weld may be soft and readily machined.

**Crystalline Structure of Iron and Steel.** — On account of the size of the grains in a cast-iron fracture, it is well known to everyone handling it that it is crystalline. A magnifying glass will readily disclose this fact. It is not, however, so well known that steel is equally as crystalline as cast iron; for instance, a piece of hardened tool steel does not appear to be crystalline, and, in the case of some high-speed steels, the fracture appears almost amorphous. It is very common to hear the expression, "That piece of steel broke because it was crystallized." It is still less commonly known, and indeed many metal workers do not believe, that wrought iron is of crystalline structure, but it is a fact. This is very readily seen by a comparatively low power magnification under a microscope, of a properly prepared specimen. Every blacksmith knows that a piece of wrought iron nicked and broken across the anvil will show a more or less crystalline fracture, although it is frequently attributed to defective material or sudden shock, or some other more or less obscure cause.

**Difference between Cast Iron, Wrought Iron, and Steel.** — The essential difference between cast iron, wrought iron, and steel is the percentage of carbon contained in them. As before stated, cast iron varies from $2\frac{1}{2}$ to $4\frac{1}{2}$ per cent, while steel contains from 0.05 to 2 per cent, wrought iron containing 0.05 per cent, or less. The essential difference between steel and wrought iron, using the terms in their commercial sense, is simply in the

method of manufacture. Wrought iron is made by puddling cast iron in a reverberatory furnace until the carbon is burned out of it. The resulting pasty mass, which is full of slag, is then squeezed in a heavy press, which forces the slag out of it, as it is more liquid than the iron. It is then reheated, passed through sets of rolls, and, if a better quality is desired, cut in short lengths, piled together, heated, and again rolled. However, it is impossible by this process to remove all the slag, and this can be detected with a magnifying glass, and is frequently seen by the naked eye in a bar of wrought iron. This slag tends to weaken the iron, not only because it has no tensile strength itself, but because it prevents the grains from coming into intimate contact.

Steel is produced by melting cast iron, either in a Bessemer or open-hearth furnace for ordinary material, or, in the case of high-quality materials for tools, etc., in crucibles. A Bessemer furnace operates by burning out the carbon entirely, leaving a mass of melted iron. The necessary amount of carbon is added by the use of ferromanganese or other high-carbon material, and the steel poured into ingots which are rolled down to the various shapes and sizes desired. The open-hearth furnace is different from the Bessemer in that there is no air blast used to burn out the carbon and that a better mixture can be obtained, because the process is slower and under better control. It produces a better and more uniform grade of steel than the Bessemer furnace, and is universally used at the present time where the best quality is desired. It is evident that the melting process eliminates nearly all possibility of slag in the metal. Slag is lighter than melted iron and tends to rise to the surface of the liquid mass, while in the puddling process the stirring up of the pasty iron allows some slag to be mixed in the metal from which it cannot later escape.

A crucible is, in reality, a small open-hearth furnace, and its use, as has been stated, is confined to tool steel, which requires careful control of the carbon and other elements in it, small quantities of which materially affect the composition and action, in service. It is also necessary to have great uniformity in the

product which can be best obtained by handling small quantities of it at a time.

**Kinds of Steel Generally Welded.** — The steels which the welder will meet most frequently contain from 0.20 to 0.45 per cent of carbon, and are called "low-carbon" steels. They do not have any elements in them, such as chromium, vanadium, tungsten, nickel, etc., which have in the last few years been alloyed with ordinary steel to obtain very high tensile strength and elastic limit, and which are mostly used in automobile construction so as to obtain maximum strength and service with the least possible weight.

The carbon in ordinary carbon steels varies with the uses to which they are put. For instance, boiler sheets will run about 0.18 per cent, spring steel about 1 per cent, steel for railroad axles about 0.40 per cent. There are many varieties of steel having carbon between these points; it will be found in practice that the steels with the least carbon weld most easily and give the best results. The reason for this is that when steel is melted, as in the welding process, the carbon is removed from it to a greater or less degree, and, unless care is taken, the steel will be burnt. The greater the amount of carbon, the greater is the danger. Steel may be overheated without burning, but, if it is once burnt, it cannot be restored, except by remelting it.

**Burning of Steel.** — Some explanation in regard to the burning of steel may be of assistance in making clearer some things that the welder will encounter, and help him to avoid trouble. As stated, steel is composed of crystalline grains, which are smaller or larger according to the details of the process of manufacture. These grains are separated from each other by thin membranes which vary in composition, thickness, and nature, depending upon the percentage of carbon, and the heat-treatment and working to which the steel has been subjected. During the process of melting steel with the torch, the metal is subjected to a very high temperature. If at this high temperature the steel is left in contact with the heat long enough, atmospheric oxygen finds its way between the grains and combines with some of the carbon,

forming carbon monoxide, forcing the grains apart, and making the metal weak and brittle. This action is intensified by the film of oxide formed by the action of the oxygen. This makes it impossible to restore the steel by heating to a lower point and forging it, as the grains will not again cohere. In other words, burning is a mechanical separation of the crystalline grains.

The welding-rod ordinarily used for welding steel contains very little carbon, being generally made of Swedish iron. In-

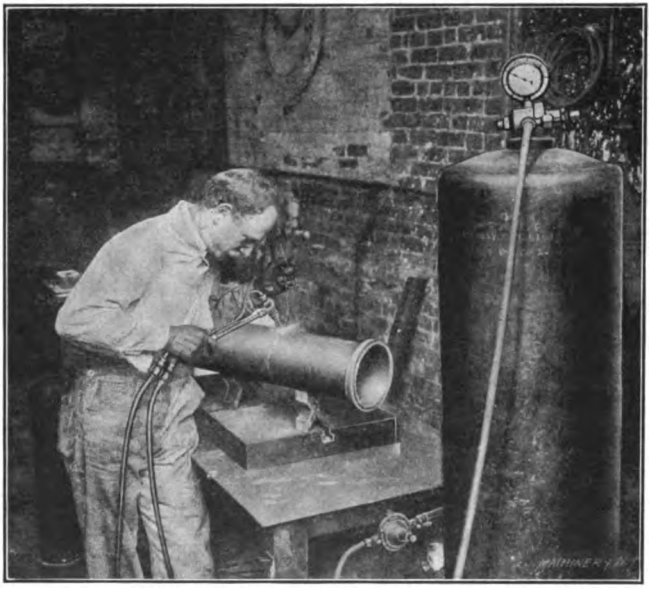


**Fig. 1. Welding together the Parts of a Drawn Steel Retort. The Operator feeds the Joint with a Special Grade of Iron Wire**

asmuch as the less the carbon the less the chance of burning, the metal added in welding is not burnt, if ordinary care is used; but, if the parts welded are of high-carbon steel, the metal next to the weld is damaged, with the result that, while the weld itself remains intact, the piece breaks next to the weld. It is impossible to burn wrought iron, as it has practically no carbon. Another thing that should be realized is that while wrought iron, which has practically no carbon, melts at about 2750 degrees F., the melting temperature of steel decreases as the percentage

of carbon increases, and steel with 1½ per cent of carbon melts at about 2300 degrees F. Not only is this true, but it is also a fact that the more carbon the steel contains, the longer time it takes to solidify after melting, the same as cast iron does, while wrought iron solidifies almost instantly. These two things, the lowering of the melting point and the length of time the metal stays melted, make high-carbon steel particularly susceptible to burning. It is, therefore, practically impossible to weld high-carbon steel, at least steel containing over 1 per cent of carbon, and the larger the section, the more difficult the work is, as it has to be kept under the influence of a high temperature for a longer time.

What has been said does not refer to steel that has simply been overheated. This condition is brought about by heating to a very high temperature, but not above the beginning of the melting range of temperature. Such steel can be restored, at least to a certain degree, by heat-treatment, and will also be helped by forging, if this is possible. It is frequently claimed that burnt steel can be restored by the use of a flux or by various methods of treatment. It is evident from the explanation given that this is not possible, and that where so-called "burnt" steel has been restored, it has not really been burnt, but simply overheated.

**Methods for Welding Steel.** — The methods used in welding steel are somewhat different from those followed in the case of cast iron. The ordinary steels handled by the welder solidify quickly; there is, therefore, a greater danger of the metal not being thoroughly united at all points, resulting in cold-shuts. The welding-wire is more likely to be burnt on account of its comparatively small section. Therefore, it is necessary that the method of handling the torch and welding-rod suit these conditions.

It is possible in the case of cast iron at times to use a V with an angle of less than 90 degrees; in fact, it is sometimes advisable to do so. In the case of steel, however, unless it is less than ⅛ inch thick, the 90-degree angle must be maintained, or the bottom of the weld will not be sound or will consist of a series of cold-shuts and laps. Again, if the torch is used to widen the

V, a series of "craters" is likely to be formed, which are exceedingly difficult to eliminate. These craters are caused by the metal in the center being colder than the metal around the edges, due to the conduction of the heat away from the bottom of the crater, or to the fact that it is not possible to get the point of the flame far enough into the hole to melt it. The only way to avoid them is to move the torch, giving the tip a circular motion around the hole, until the surrounding metal is brought to a temperature sufficiently high to prevent the conduction of heat, when a sudden lifting of the torch will allow the metal to flow together.

In the case of thin sections, this circular motion of the torch has been found to be the most satisfactory way to weld steel.

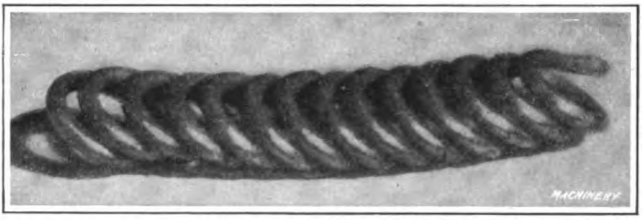


**Fig. 2. Graphic Illustration of Movement of Torch when Welding Steel**

It is very difficult to describe, but once seen it is easy to understand. The author knows of nothing that it resembles so much as a helical spring crushed down sideways, as shown in Fig. 2, the torch tip following the path of the spring wire, advancing a little, as from coil to coil, at each revolution. The speed of rotation and advance have to be made to suit the work. Of course, in heavy welds this cannot be done, as metal is added. In this case, the wire should be used as a sort of a center around which the torch is oscillated, the path being somewhat more than a half circle. In this case, the wire should never be removed from the pool of melted steel, as the tendency is then to burn it. The flame should not be turned directly against the welding-wire, but kept far enough away from it so that while the wire is melted, the flame does not touch it; and the flame should not be kept on the metal any longer than is absolutely necessary.

Steel does not form a comparatively large melted pool, as in the case of cast iron, and for this reason, and because of its rapid solidification, it is necessary to be careful about welding the edges of the pool. As soon as the metal is brought to the melting point, if the torch is raised suddenly, the metal which has been blown into a shallow cup shape by the force of the blast will at once become level and solidify. Hence, a good steel welder keeps his torch constantly in motion, using the rotary movement and quick elevation.

**Size of Torch Tip.** — From what has been said of the danger of burning steel, it is evident that it is important to use the right size of tip, neither too large nor too small, and also to provide sufficient sizes of wire to prevent the burning to which it is liable. The author finds that three sizes are sufficient for the majority of the work of an ordinary welding shop — $\frac{1}{16}$, $\frac{1}{8}$, and $\frac{3}{16}$ inch.

**Importance of Neutral Flame.** — It is evident that, on account of the affinity of iron for oxygen at a high temperature, the flame should be neutral, and not only this, but there should be no oxygen escaping from the torch where it can combine with the melted metal. This is particularly important in the case of steel. The author knows of instances where it was impossible with a certain type of torch to produce satisfactory welds, while another, which used less oxygen, gave entirely satisfactory results. This emphasizes the importance of good apparatus.

**Heat-treatment of Welded Steel.** — It should be remembered that the weld is only a casting, and that it has received no forging or other treatment to refine the grain and to make the metal of better quality. In a few cases an extra amount of metal can be added to the weld and the piece drawn out with a hammer, or otherwise worked to produce a stronger metal, but this cannot generally be done where the dimensions of a piece must be maintained. It is possible, however, by heat-treatment, to increase the tensile strength and elastic limit of the metal to a certain extent.

The physical characteristics of a weld in steel depend con-

siderably upon the heat-treatment to which it is subjected after the welding is done. This statement is true, of course, of any piece of steel whether welded or not, and the higher the amount of carbon, the greater the effect of a proper heat-treatment. As already stated, it is generally the practice to use, for welding steel, a wire either of pure Swedish iron, or of steel very low in carbon. This is done whether the material to be welded is wrought iron, which contains very little carbon, or axle steel containing 0.4 per cent of carbon, and, in many cases, such welding-wire is used for steel containing still higher carbon. Now, inasmuch as the heat-treatment that will give the best physical characteristics depends upon the carbon content of the steel, it is evident that, unless the piece welded is of a steel very low in carbon, the heat-treatment, to obtain the best results, should be different for the added material than for the original. It is, of course, impossible to do this, so that a compromise must be effected. Again, it must be remembered that a weld is a casting, and that the necessary temperature for annealing a steel casting is considerably higher than for a piece of forged steel containing the same percentage of carbon. Again, the higher the carbon content, the lower the heat-treatment temperature at which the best results are obtained, so that on one hand there is in the weld a material low in carbon which is a casting, and which requires a high heat-treatment temperature to obtain good physical characteristics, and, on the other hand, there is in the original material, possibly a steel very high in carbon, which is a forging. Both conditions require a lower temperature to obtain the best results, so that, if the weld is heated enough to refine the grain, the original material is overheated, and while, in the case of medium-carbon steels, this does not affect the strength of the original material very greatly, it does affect it somewhat.

**Heat-treatment Temperatures.** — It has been frequently stated that a weld can be annealed by heating to the point at which an ordinary horseshoe magnet just ceases to be attracted by the hot steel. This is about right in the case of a piece of forged steel, but this temperature is not high enough in the case

of a weld; a temperature between 1750 and 1800 degrees F. is necessary to break up the coarse structure of a weld made with soft steel welding-wire. If 1800 degrees F. is not exceeded, no serious damage will occur to steel containing less than 0.3 per cent of carbon; but the higher the carbon content, the greater the damage to the original material by such a high heat-treatment temperature.

It is not possible in many cases to heat-treat a welded piece; and in these instances the physical characteristics of the weld and adjacent material cannot be changed. This is the reason why it is so important to use good judgment in steel welding, and not to weld pieces the original condition of which has been obtained by carefully applied heat-treatment. Even in the cases where heat-treatment can be applied, it is impossible to obtain the same results as in the original piece.

The Committee on Heat-treatment of the American Society for Testing Materials recommends, for annealing carbon steel castings, the following approximate temperatures:

| Carbon, Per Cent | Temperature in Degrees F. |
|---|---|
| Up to 0.16 | 1700 |
| 0.16 to 0.34 | 1600 |
| 0.35 to 0.54 | 1560 |
| 0.55 to 0.79 | 1525 |

The following statement is made by Speller in the above connection: "It will be found in annealing large quantities of soft steel under 0.10 per cent of carbon that the temperature given is about 90 degrees F. too low to secure uniform refinement of grain."

With regard to annealing welds by heating to the temperature at which a magnet loses its attraction for the heated metal, this loss of magnetic power occurs at from 1330 to 1375 degrees F. on heating. It would, therefore, appear evident that the use of a magnet will not give satisfactory results, and that a pyrometer is really the only means for obtaining proper annealing temperatures.

**Heat-treatment of Alloy Steels.** — The heat-treatment of alloy steels is quite a complicated process, and can only be carried out with the proper apparatus. No welding shop, as a

rule, has any facilities for doing this work, and as the ordinary welding-rod does not have the necessary ingredients to make a truly homogeneous weld, and as at the best the weld is only a casting, the welding of alloy steels should be avoided. It is true that in special cases, and where there is a knowledge of the character of the metal, fair results may be obtained, but this information is not possessed by the average welding shop doing repair work, and it is best to restrict the welding operation to materials which it is known can be welded successfully, because no good comes from attempting work beyond the limitations of the process.

**General Considerations.** — It would appear at first sight perfectly feasible to use welding as a process for joining steel parts wherever riveting is now employed. In many cases it is possible to do so, but in many other cases it is not advisable. While a riveted joint is imperfect in many respects, and a poor mechanical construction, yet its strength and the practices followed in making it are so well known that the riveted joint is certain to remain. The lack of knowledge of the technique of welding, the scarcity of competent welders, and the prices of the gases often make the cost of welding prohibitive and the quality of the work uncertain, when an attempt to replace a riveted joint is made. The time will come when large structural work will be done by the oxy-acetylene process. However, the welding of steel by this process is being extended every day, and things are done now which were not thought possible a few years ago. Therefore, the further extension of the possibilities may be reasonably expected.

Many of the defects which occur in a cast-iron weld are likely to occur in a steel weld, some of them being more frequent and more difficult to avoid. The most serious is a lap of the hot metal on top of the cold; this is an exceedingly common defect with new welders. It is much more likely to occur in a large piece than in a small one; in fact, the larger the piece of steel, the more difficult it is to make a sound weld. The difficulty is caused either by the addition of too much steel at once, so that it flows over onto the metal underneath without being welded

to it; by dropping the metal from the welding wire onto the metal underneath, instead of keeping the end of the wire in the pool of melted metal; or by carelessness in not thoroughly welding the edges of the melted pool to the rest of the metal. The metal is far more likely to bridge in the case of steel than in the case of cast iron, particularly where the pieces are V'd from both sides, when the weld is started at the bottom of the second V after turning the piece over.

Fig. 3 shows an enlarged view of a defective weld, the original piece being $1\frac{1}{2}$ inch in diameter. A large number of laps and cold-shuts will be distinctly noticed. The polishing to which this piece was subjected has brought out the difference between the original metal and the added material, and it appears clearly that the weld was imperfectly made, because this added material shows on four sides. In making a steel weld, the edges of the weld should be built out somewhat beyond the sides of the original pieces, so that it will not be necessary to burn down any on the sides to eliminate imperfect work. The weld should be so made that any roughness left on it when ground off will leave sound metal all the way around. There is always great danger of laps or cold-shuts when any other course is followed. This is particularly applicable to round pieces, which are more difficult to weld than rectangular ones.

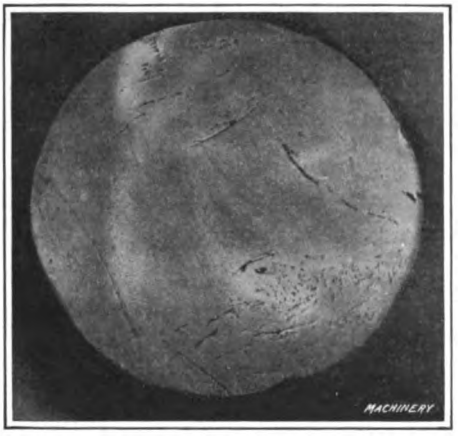



**Fig. 3. Section of Defective Weld in Steel Bar**

**Welding High-speed Steel to Machine Steel.** — To weld high-speed steel to ordinary machine steel, first heavily coat the end of the high-speed steel with soft special iron, obtainable from the makers of welding outfits. This can be done without

heating the high-speed steel to the burning point. After cooling, the high-speed steel can be welded to ordinary machine steel without burning, but experience is required to make a good weld of this kind.

**Welding Cast Iron to Steel.** — To weld cast iron to steel, cast-iron rods are used as welding material. The steel must be first heated to the melting point, as cast iron melts at a lower temperature. A very little cast-iron flux should be used.

**Welding Steel Castings.** — Certain grades of steel castings can be welded more easily than ordinary rolled steel, but other grades, especially of high carbon content, are very difficult to weld, and some cannot be welded at all. When difficulty is experienced, the addition of one or two drops of copper, melted into the weld, will cause the metal to flow and a fairly good weld can be made, but copper is likely to harden the metal so that it cannot be machined except by grinding.

**Spots in Welding.** — When making heavy welds, there often is a spot in the middle of a weld where the metal refuses to flow, because the metal is not hot enough surrounding this spot, the heat being absorbed by the cold metal; consequently, the added metal is chilled. To remedy this, play the flame in a radius of from $\frac{1}{2}$ to 1 inch around the refractory point until the surrounding metal is at a white heat; then apply the flame to the spot itself and it will quickly unite with the other molten metal.

**Welding Malleable Iron.** — The welding of malleable iron is difficult, for several reasons. If malleable iron is raised to the melting point and kept there for any length of time, the metal becomes spongy and changes to what is practically cast iron. Those who have tried to weld malleable iron know that the results are usually unsatisfactory. The metal either becomes so hard that it cannot be machined, or it is brittle, or both. The reasons for this lie in the nature of the metal, which is not generally understood, because of the comparative lack of knowledge of its method of manufacture. To explain sufficiently why these difficulties exist and how they may be overcome, it is necessary to consider somewhat the metallurgy of cast iron and the changes which take place during its conversion into malleable iron.

**Production of Malleable Castings.** — It is necessary in making malleable iron to use white or chilled iron castings, because graphite, being an inert substance and not acted on by the malleabilizing process, cannot have its condition changed by this process, so that the carbon in iron from which malleable castings are to be made must all be in the "combined" condition, and not "free," as in gray-iron castings. Cast iron has a larger percentage of carbon than steel, and it would appear that if enough of the carbon could be removed from cast iron, so that it had about as much as ordinary steel, a product resembling steel would be the result. This was the aim of the inventor of malleable iron, Reaumur, and the process was carried out by packing the white cast-iron pieces in decarburizing matter, such as oxide of iron, and subjecting the pieces so packed to a high temperature for a long enough time to reduce the percentage of carbon to the desired point. It was found that the time required to carry the action entirely through a piece was considerable, and, therefore, the cost was excessive; so that only thin pieces are now subjected to this process. Inasmuch as it was desirable to treat heavier pieces, it was found by experiment that it was not necessary to reduce the percentage of carbon all the way through the piece, but that, by proper treatment in the annealing oven, the carbon could be changed into a third form to which has been given the name "temper" carbon, to distinguish it from "combined" and "free" carbon, although temper carbon is identical with graphite as far as can be determined.

The first kind of malleable iron can generally be welded with steel, as it is really a crude steel. The second form, however, is the one that presents the difficulties spoken of above, and it will now be evident why these difficulties exist. Cast iron, when changed into steel, cannot, by melting under the torch, be changed into cast iron again; but in the second kind of malleable iron, the carbon is not removed, but only changed into another form. Therefore, when melted, all the conditions are favorable to the reformation of chilled iron, which is exactly what occurs; so that the resulting weld is, as previously stated, hard and brittle.

**Procedure in Welding Malleable Iron.** — Malleable iron can be welded with a cast-iron welding-rod and a sound weld obtained, but it is not homogeneous. In some cases, it may be entirely satisfactory; for instance, where special strength is not required, or where no finishing, except by grinding, is to be done. For all ordinary work, it has been found that the use of manganese-bronze as a welding-rod with a little borax used as a flux will make a weld, which, while not homogeneous, will answer the purpose. The precautions to be observed are as follows:

1. Malleable iron must not be melted, but only brought to a temperature at which the bronze will alloy with it. This is somewhat above a good red heat, and is easily ascertained by a

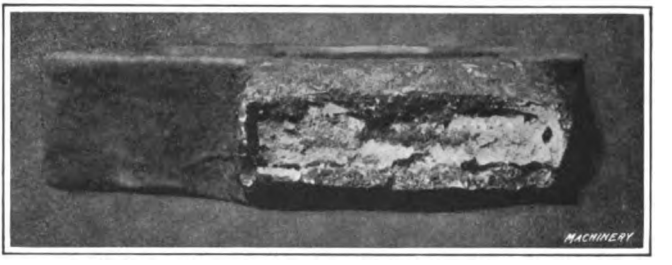



**Fig. 4. Malleable Iron improperly welded**

few trials. A neutral flame must be used, and it is generally advisable to add surplus metal to the weld.

2. It is a good thing for the welder to observe the action of the second kind of malleable iron under the torch. It will be noticed in a fresh break that the outside shell, say, $\frac{1}{32}$ inch deep, is white, and under the torch acts like steel, but the further in toward the center the flame is used, the more will the action appear like that of cast iron, and it will be found that steel cannot be used in welding. The metal also tends to become full of blow-holes. If the torch is used to melt such a piece, and it is then allowed to cool off and the surface ground and polished, it will be found to consist of white iron, except the thin outside shell. If a weld is made using a malleable iron welding-rod, it will be found that the weld is very brittle, and, when broken, will show the characteristic appearance of white iron. Of course,

such a weld may be made into malleable iron by putting it through the regular process, but this is not possible in repair work, although it is in certain manufacturing processes. Therefore, the use of bronze appears to be the only present solution of the difficulty, and it would seem that the metallurgy of malleable iron makes impossible any other solution.

**Effect of Improper Welding.** — Figs. 4, 5, and 6 are good illustrations of the structure of malleable iron and of the damage done to it by improper welding. Fig. 4 shows the section nearly full size, while the others are enlarged to show the defects more clearly. There is considerable difference in appearance between

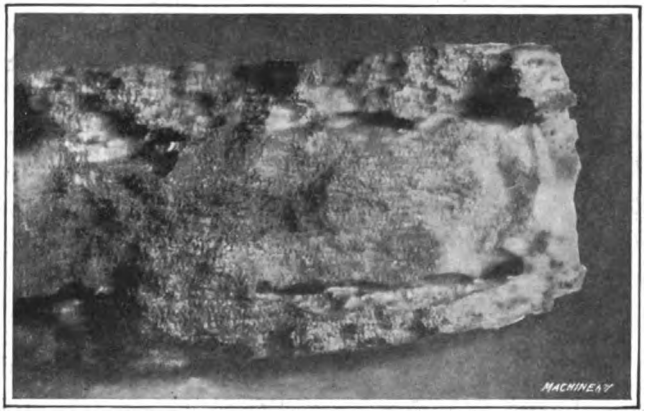



**Fig. 5. One End of Piece shown in Fig. 4, magnified**

the outside and inside of the piece. The piece was originally welded with steel. The second break occurred outside the weld, because the added steel at the first weld was considerable in amount, and, therefore, stronger than the section shown.

In Fig. 4 the difference between the center and the outside of malleable iron is very clear, the outside being darker and of steel, while the inside is of cast iron, but with the carbon changed to the "temper" form. Wherever the added steel is welded to the steel casing, the metal at the junction of the cast iron and steel has been seriously damaged, causing holes; and where there is no added steel, or where the weld between the two steels has been defective, as from *A* to *B*, Fig. 6, no apparent damage

has occurred. An examination of the piece shows that no extra metal was added from *C* to *D* or from *E* to *F*, and that on account of the defective weld between the two steels at *A* and *B*, no apparent damage is done to the metal below.

In repairing the break, it was found impossible to cut the defective pieces out with a hacksaw, as hard spots were encountered as soon as the added steel was cut through. It was, therefore, necessary to grind the defective parts away. This left a space which had to be filled up, which was done with manganese-bronze, the weld being made and heavily reinforced with the

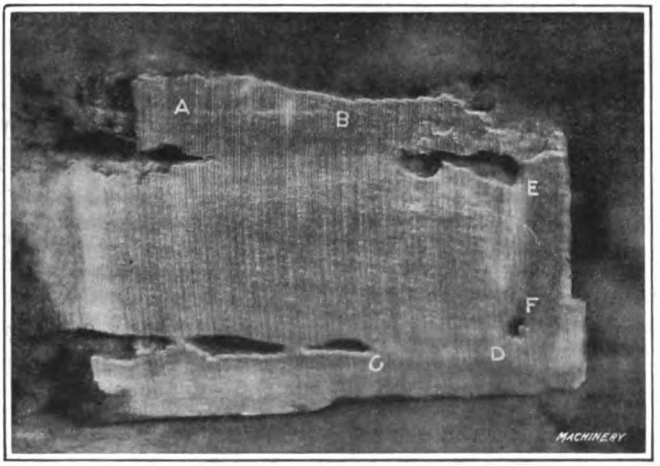



**Fig. 6. The Other End of Piece shown in Fig. 4, magnified**

same metal. The hard spots were caused by the malleable iron changing back to white or chilled iron under the high heat used.

**Welding Copper and Copper Alloys.** — Under this heading will be treated the welding of pure copper and also the various kinds of brass and bronze which are made with copper as the principal ingredient. Copper is not a difficult metal to weld if precautions are observed to avoid several peculiarities in its action when under a high temperature. It has the property, when melted, of absorbing gases to a very considerable extent. On cooling, these gases are given out and make the weld porous. Copper also oxidizes readily when melted and this oxide alloys

with the copper, making it brittle and spoiling the weld. As it is impossible to work out this oxide, methods must be used during the welding to eliminate it, or preferably, to avoid it altogether.

**Use of Phosphorus in the Welding-rod.** — It has been known for a long time that a small percentage of phosphorus added to copper or copper alloys eliminates blow-holes and makes a sound, dense casting; hence, the welding-rod for copper should contain the proper percentage of phosphorus. Traces of phosphorus do not injure copper, but an excess is not good, so that proper care and accurate knowledge are necessary to produce the proper welding material. Copper has great heat-conducting power — more so than any of the other common metals — and while it melts at about 1930 degrees F. the heat is removed so rapidly by conduction that it is necessary to use a larger tip than for iron and steel; and preheating of the parts is more necessary in order to reduce the gas consumption than in the case of other metals. The radiation from the heated metal may be retarded by covering it with asbestos. On account of the affinity of copper for oxygen, and on account of the fact that an excess acetylene flame produces blow-holes in the weld, even with good welding material, it is necessary to use a neutral flame, although it will be found that instructions are sometimes given to the contrary.

**Miscellaneous Precautions in Copper Welding.** — Another peculiarity of copper is its brittleness at a temperature somewhat above a dull red, while at or below this temperature it can be readily forged. The welder must, therefore, be careful to observe contraction strains as the metal is cooling down. Full and uniform preheating will help to avoid this difficulty. It is not often, however, that a repair welding shop is called on to work with copper, and when it is, the work is generally the simple welding of rods or bars together. In such cases, enough metal should be added to make a considerable "swell" around the weld, and, after heating to a dull red, it should be forged. Care should be taken not to heat it too hot, and after the forging is done, the work should be allowed to cool off slowly, unless it has to be bent, when the whole piece should be heated to a

dull red and annealed by plunging it in water, this operation being repeated frequently if the piece requires much working, as the working of the metal causes it to become brittle.

A method for welding copper, which is claimed to give very satisfactory results, consists in placing two pieces of copper in position, so that they can be heated at the proper point by the oxy-acetylene torch until the requisite degree of softness is attained. Complete reduction is then effected in the flame by the use of purified hydrogen, and the welding is completed by hammering. The joint is said to be invisible and the metal at the weld is claimed to be as homogeneous in every way as the remainder of the metal welded; but this method is not applicable in ordinary cases, although it may be useful in certain manufacturing operations.

**Recapitulation of General Directions for Welding Copper.** — In welding copper, use the same kind of flame as for steel, but a much larger tip for corresponding dimensions, because of the great radiating property of copper. Preheating is necessary when a large piece of copper is to be welded, as otherwise so much heat from the torch will be dissipated by radiation that little will be left for fusing the metal. Copper will weld at about 1930 degrees F.; hence, the flame need not have so high a temperature as for steel and it must not be concentrated on so small a surface. On account of the radiation, however, the total quantity of heat must be greater. Welded copper has the strength of cast copper, but can be rendered more tenacious by hammering. The radiation of heat from copper can be considerably lessened by covering it with asbestos sheets while heating.

**To Weld Copper to Steel.** — To weld copper to steel, first raise the steel to a white heat (the welding point); then put the copper into contact with it and the two metals will fuse together. When the copper begins to flow, withdraw the flame slightly to prevent burning.

**Copper Alloys.** — Copper alloys are divided into two general classes, brasses and bronzes. The principal ingredients in the former are copper and zinc, and in the latter, copper and tin.

There are a great number of these alloys differing materially in composition, and as the welder cannot know the exact composition of each, and as, even if he did, it would be impossible to make the proper mixture to produce a truly homogeneous weld, a welding material should be kept in stock that will cover all of the cases with which he meets. It is the general experience that manganese-bronze or Tobin bronze is very satisfactory for all brasses and bronzes.

In welding brass, when the metal is brought to a certain temperature by the torch, white fumes suddenly disengage themselves, and, in the case of a large piece, these will chill and condense on the cooler surfaces. This is due to the volatilization of the zinc, the fumes being white zinc-oxide; care should be taken not to breathe these fumes. The proper point at which to add the metal is just after the surface of the piece begins to boil and bubble, and as manganese-bronze contains a large percentage of zinc, any zinc that may be lost in heating will be partly replaced by the metal in the welding-rod. In the case of bronze, the zinc loss does not occur, but the bubbling of the surface of the heated piece occurs and determines the temperature at which the metal should be added. Manganese-bronze is quite fluid and unites nicely with the broken parts. It is advisable to use a small amount of borax as a flux to clean the surface, although no more than is necessary should be used.

A neutral flame is the proper one to use for both brass and bronze. Keep the point of the white flame slightly away from the weld, according to the thickness of the piece, so that the heat will not be sufficient to burn the copper in the brass or to appreciably volatilize the zinc. If a white smoke appears, remove the flame, as this indicates excessive heat. Brass and bronze are both good heat conductors, although not as good as copper. Generally the same size tip as for cast iron will be satisfactory. Care should be taken to avoid laps or cold-shuts in a weld, which is readily done if the metal is kept at the proper temperature. These metals are generally easy to weld, and, as manganese-bronze is exceedingly strong, the weld is generally the strongest part of the piece.

**Filling Blow-holes.** — To fill large blow-holes in brass or copper castings, preheat the casting to a temperature between 200 and 400 degrees F. below the melting point, or to a bright red color. Have some of the same metal melted in a crucible ready to pour, then apply the torch to the blow-hole to be filled and when the walls of the hole have been brought to the melting point, gradually pour in the metal, keeping the walls fused by using the flame. Continue mixing the poured metal with the molten metal of the walls, until the blow-hole is filled. This method, however, is only used when a sound job is not required, but the filling is done for appearance only. It is not a generally satisfactory method, as "burning-in" does not produce homogeneous metal, and one cannot see what is taking place at the weld.

## CHAPTER VII

### WELDING ALUMINUM

ALUMINUM is seldom used in its pure condition, as it is too soft, and in repair work, only the aluminum alloys — principally in the form of crankcases, transmission cases, and other automobile parts — are encountered. In the United States, the usual alloy contains, at the present time, about 93 per cent of aluminum and 7 per cent of copper. In the past, quite a number of parts were made from a zinc alloy containing approximately 90 per cent of aluminum and 10 per cent of zinc, but in foundry practice it was found that the alloy became brittle at a temperature just below solidification, so that many castings were defective on account of cracks due to shrinkage and had to be thrown out. The copper alloy, while not quite so strong at ordinary temperatures, does not have the tendency to crack that the zinc alloy has; this is fortunate for the welder, as cracking is likely to occur in many cases, particularly in a complicated piece, due to the contraction strains.

**Flux for Aluminum Welding.** — It is frequently stated that it is impossible to make a sound weld in aluminum without a flux which will destroy the oxide. Aluminum oxide is exceedingly resistant to the action of any acid or alkali even at a high temperature. Therefore, the flux used in welding must be very severe in its action. The danger in using some kinds of flux is that an excess, unless it is removed in some way, will damage both the metal in the weld and that surrounding it. Another objection to the use of flux is that the surfaces to be joined must be thoroughly cleaned, because the flux is designed to remove oxide of aluminum and not grease and dirt, which are always present in repair work. The time occupied in cleaning the dirt out of the crack or break is considerable, and in most cases the weld can be made without flux in the time required to clean the

piece thoroughly. Again, it is not possible, even by the use of a flux, to avoid some porosity in a weld; and further, in the best aluminum castings there may be, and frequently is, greater porosity than in a well-puddled weld. In view of these facts, the author doubts the advisability or necessity of using flux on castings. (See Chapter III.)

**Welding without Flux.** — The method recommended, and which is used by many experienced welders in the case of cast aluminum, is to thoroughly puddle it without any preparation, except wiping off the dirt and grease. There is an additional

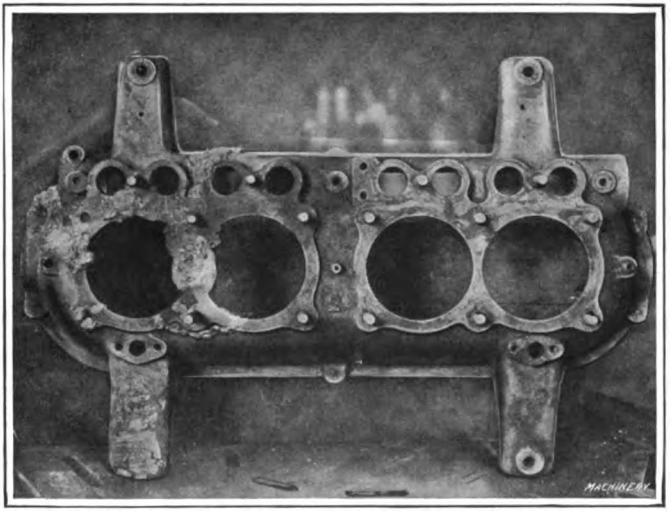


**Fig. 1. Crankcase damaged by Use of Flux and Improper Welding**

advantage in not making a V at the break in the case of aluminum, which is that the sections are generally thin and the contraction of the weld is better resisted by the piece being allowed to remain its full thickness, although of course the contraction is not entirely avoided.

**Result of Using too Much Flux.** — Figs. 1 and 2 show the damage that can be done by improper treatment. This type of crankcase generally is not seriously damaged when a connecting-rod or bolt gives way, which apparently was the cause of the damage. The welder used altogether too much flux on it, and

was unable to obtain satisfactory results. The case was so seriously damaged by this treatment that the cost of putting it in proper shape would be much greater than if it had been properly repaired in the first place, and would be so high that it would probably be inadvisable to spend the money on it. This is a good illustration of the incidental damage that can be done by improper welding. Undoubtedly, the welder who attempted to do this job had had little, if any, experience, and had no instructions in the principles of the art.

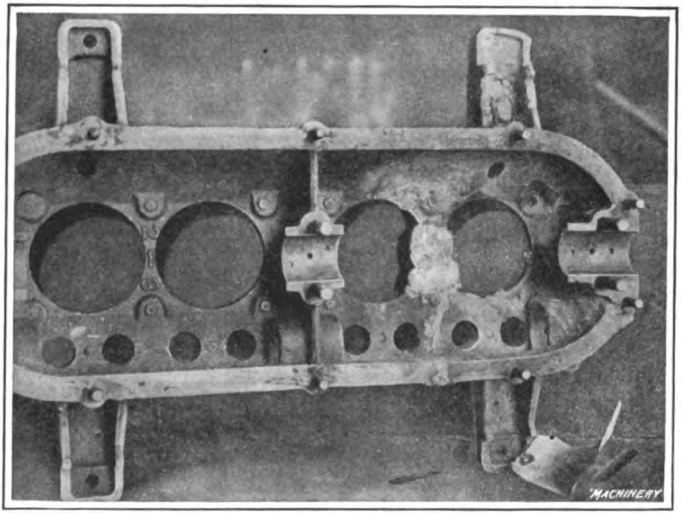



**Fig. 2. Bottom View of Crankcase shown in Fig. 1**

**Procedure in Welding.** — A puddling rod such as shown in Fig. 3 has been found most satisfactory, although other shapes are used. In all ordinary cases, the metal should be melted with the torch until the bottom of the crack is reached, using the puddling rod all the time, and the metal should be allowed to sink below the lower surface of the crack, forming beads. These beads can be removed afterward, either by the torch and puddling rod, or by chipping or filing. In welding thick pieces, the work must be done from both sides. In this case, too much of the welding should not be made on one side at once. It is better to weld, say, 2 inches, on the first side, and then turn the work

over and finish welding the 2 inches on the other side, then proceed along 2 inches further, and again turn the piece over and weld 2 inches more on the first side. The reason for this is that aluminum is somewhat brittle near the welding temperature, and cracks are likely to develop, particularly in a long weld, if all the weld is made on one side first, and then finished on the other. On account of this brittleness, a weld in aluminum must be made quickly. Slow work is fatal to good results. It is occasionally necessary in a long weld to have two welders start at the middle of the crack, and work toward the ends, to avoid shrinkage cracks.

**Character of Flame.** — It is frequently recommended that a flame with a slight excess of acetylene should be used when welding aluminum, to prevent oxidation and to reduce the tem-

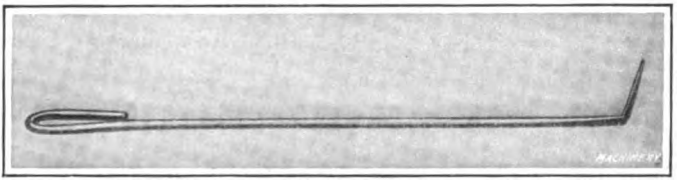


**Fig. 3. Puddling Rod used when Welding Aluminum**

perature. A very slight excess is all that is needed for the former reason, but it has not been found, in practice, necessary to use such a flame, and a neutral flame is recommended. The practice of using an excess of acetylene doubtless originated in the early days of the process, when nearly all torches gave an excess-of-oxygen flame, which later and better designs will not do, and it is not now necessary, with a good torch, to use an excess-of-acetylene flame. With regard to the flame temperature, it is obvious that if it is too high, with a very slight excess of acetylene, a smaller size of tip should be used. There is no advantage in burning more gas than necessary.

**Preheating.** — It is always safest to preheat an aluminum casting to about 500 degrees F., to take care of the contraction strains as much as possible. During the preheating, the piece should be covered with asbestos paper, to keep the temperature as uniform as possible. This covering should not be re-

moved while welding, except where necessary. After welding, the part should be reheated, and either allowed to cool in the fire, or be wrapped in asbestos paper and allowed to cool slowly and free from the influence of drafts. It is generally true that if no crack appears in a few minutes after welding, none will occur at all; therefore, it is well to leave the piece in the fire and examine it at a short interval after welding. If the weld is sound, it can then be packed away with little fear of trouble.

In many cases, as with other metals, it is not necessary to preheat; as, for instance, small pieces, or where a lug or projecting piece is broken off, the break being at some distance from the main part of the casting. In fact, in such instances as the breaking off of a lug in an aluminum manifold, preheating is dangerous, as too much heat will tend to bring the body of the piece to the temperature at which it will suddenly sink away from its original shape. The beginner will also, until he learns by experience, have the same trouble when he lifts up a piece to turn it over before it has set solidly, as it will either distort or fall to pieces.

**Manipulation of Welding-rod and Torch.** — Too much metal should not be added from the welding-rod at one time, and what is added should be thoroughly puddled with the welding-rod while it is being added and afterward, until there is a melted pool at that point and the proper union has been made with the surrounding metal. The surplus metal should be scraped off with the puddling rod while in a pasty condition, as it contains much oxide, and the welder should be sure to make a good junction at the edges of the weld. The manipulation of the torch with one hand and the welding-stick with the other, the latter having to be laid down and the puddling-rod picked up at frequent intervals, is rather difficult. Some welders find it easier to hold the torch in the left hand, although ordinarily right-handed; others find the opposite way to be the easier. In either case, the trouble is caused by the difficulty of working with both hands at once.

When adding the metal from the welding-stick, it should be continually rubbed into the melted pool in order to avoid oxi-

dation and to work the oxide to the surface. A beginner should weld and break quite a number of test-pieces before he attempts any important work. He should not be discouraged at the result of his first attempts, which are certain to be unsatisfactory, much more so than with any other metal, although aluminum is a very easy metal to weld, after the difficulties in handling it have been overcome.

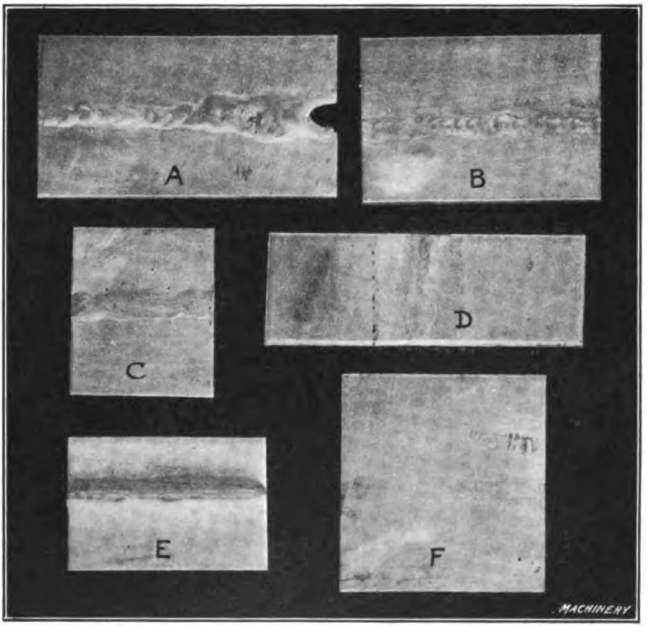



**Fig. 4. (A) Weld made by Beginner. (B) Fusion not Thorough. (C) A Good Weld on 0.048-inch Stock. (D) A Good Weld on 0.116-inch Stock. (E) Flanged Weld improperly done. (F) A Hammered Flanged Weld**

**Welding Sheet Aluminum.** — The preceding paragraphs refer especially to repair work on castings. In the case of sheet metal, the procedure is different. Before commencing to weld, the edges of the joint are carefully squared, cleaned, and fluxed, frequently by dissolving the flux in alcohol and painting it along the edges to be welded. Practically all work, except sheets of very light gage is butted, the thin sheets being lapped or hooked; or it will be found advantageous at times to turn up

the edges at right angles so as to form sufficient excess of metal for filling in the joint. By this method it will be clearly seen that heterogeneous metal does not enter the weld, the joint being entirely composed of metal identical with the surfaces to be joined.

The flame is usually applied at an angle of about 45 degrees to prevent burning, but for thick sheets of $\frac{3}{16}$ inch and upwards

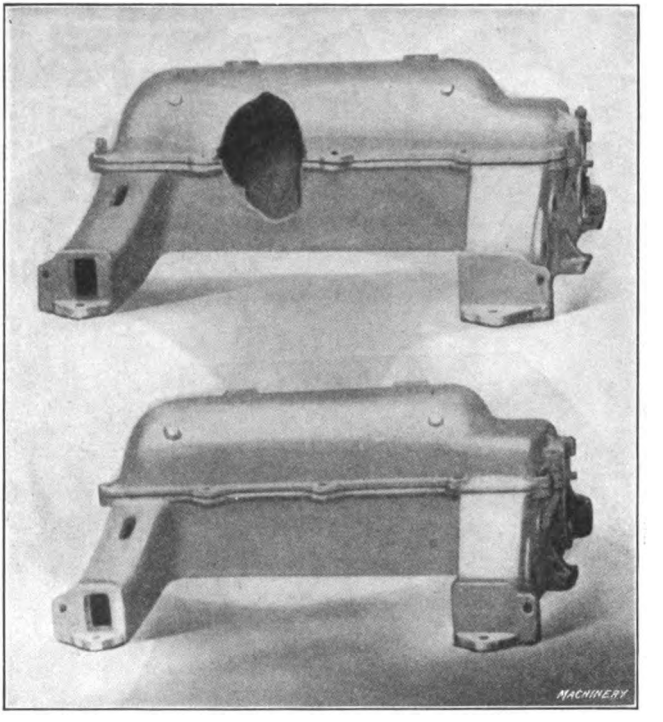



**Fig. 5. Fractured Aluminum Gear-case before and after being welded with Oxy-acetylene Blowpipe**

it may be directed nearly perpendicularly upon the work. It must be remembered that the flame gives a temperature about four times the melting point of the metal, and that there is quite a blast from the gas pressures in the torch, so that, in thin metal, there is nothing to prevent holes from being formed in the aluminum, except the dexterity of the worker. An expert can make good welds in sheet aluminum 0.008 inch thick. Speed

is the prime requisite, and the welder should be able to run down the joint with the torch and rod at a uniform rate. In view of the great expansion of aluminum when heated, a considerable opening must be left at one end when commencing to weld, which opening will, of course, close up as the work proceeds. While the thermal conductivity of aluminum is higher than that of iron, this is offset by the lower melting point, so that generally the same size of tip can be used for aluminum as for cast iron of the same thickness.

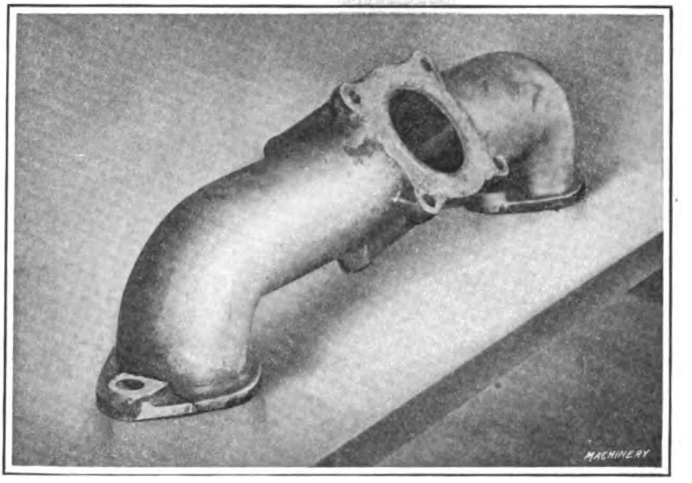



**Fig. 6. Aluminum Manifold with Broken Lug**

**General Requirements in Welding Aluminum.** — In welding aluminum with the oxy-acetylene torch, it is essential that the acetylene and the oxygen used must be in a state of high purity, as at the great temperature of the welding flame, aluminum tends to absorb nitrogen, and if this impurity exists in the oxygen it will render the work brittle and unreliable. It is known to those who have attempted to weld aluminum by means of the oxy-acetylene flame that, when two pieces of the metal are to be welded together at their edges, the melted parts do not flow together properly, as in the case of iron where the melting point of the oxide is lower than that of the metal. The molten aluminum spreads in spherical form under the influence of the

welding flame. These metallic pellets consist of pure aluminum within a coating of alumina (oxide of aluminum) which has great power of resistance to the flame, and, on cooling, the edges of the metal remain unjoined; hence, the need of a flux to remove the oxide film and permit the fused metal to flow satisfactorily together.

**Skill Required by the Welder.** — The success of welding aluminum autogenously depends to a great extent upon the intelligence and ability of the operator. It is possible for a com-

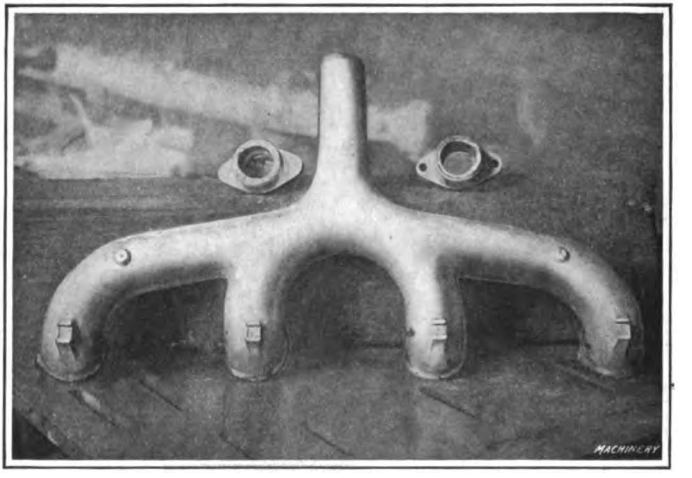


**Fig. 7. Aluminum Inlet Manifold with Broken Carburetor Flange**

petent welder, at his own discretion, to give a greater or less strength to the welded part, and for this reason it is impossible to draw conclusions from the work of one operator as to the work of another. An expert in aluminum welding is distinguishable by his care in the preparation of the surfaces to be welded; judgment in preheating and reheating (or annealing) of the work; the choice of a well-constructed torch; the determination and maintenance of the correct proportions of oxygen and acetylene issuing from the nozzle of the torch; in the entire application of the system; the estimation of the area to be fused in each partial operation; the manipulation of the welding flame at the right moment when fusion has proceeded so far that com-

plete welding is assured; the dexterity in preventing the deformation of the metal under the torch; and lastly, the rapidity and ease of the operation, thereby preventing the overheating of the metal and the avoidance of damaged welds. Most of these requirements, of course, apply to the welding of other metals also.

**Examples of Aluminum Welding.** — Some specimens of welded sheet aluminum are shown in Fig. 4. The aluminum sheet *A* is 0.064 inch thick and was welded by a beginner, with the oxy-acetylene torch. The weld *B* has a good appearance

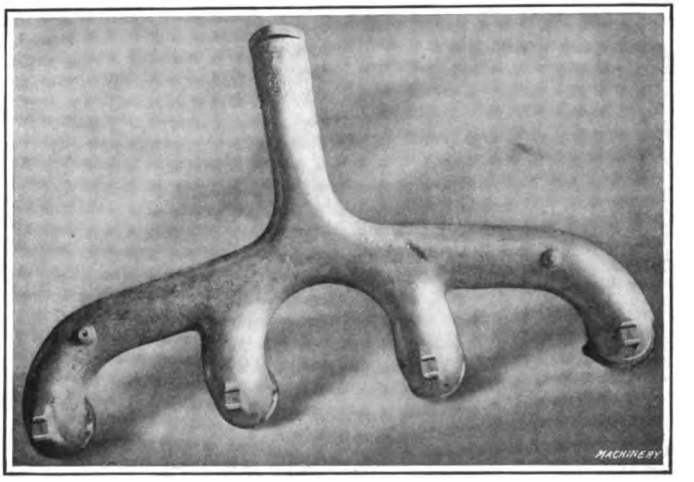



**Fig. 8. Aluminum Inlet Manifold — Repairs Completed**

on the top surface, but thorough fusion has not occurred. Good welds are shown at *C* and *D;* the aluminum sheet *C* is 0.048 inch thick, and *D*, 0.116 inch thick. The flanged weld *E* was improperly made; thickness of aluminum, 0.048 inch. The flanged weld *F* was properly made and afterward hammered.

**Welding Aluminum-zinc Alloys.** — Alloys of aluminum and zinc present much the same difficulties as are encountered in welding aluminum-copper alloys. These alloys are now extensively used in the automobile, aeronautical, and kindred industries where strength combined with lightness is a necessity. A typical automobile repair job is shown in Fig. 5, which illustrates the crank-chamber or gear-case. The upper view shows

the fractured gear-case, whereas the lower view shows the same case repaired by oxy-acetylene welding.

**Feeding Rods.** — As already mentioned, the added metal should have practically the same composition as the material being welded. The necessary alloys of aluminum and zinc are not always as readily obtainable as feeders, especially in the form of strips, which are preferable, so that many operators use pure aluminum during the welding process. However, the adding of molten metal from feeders of pure aluminum should be

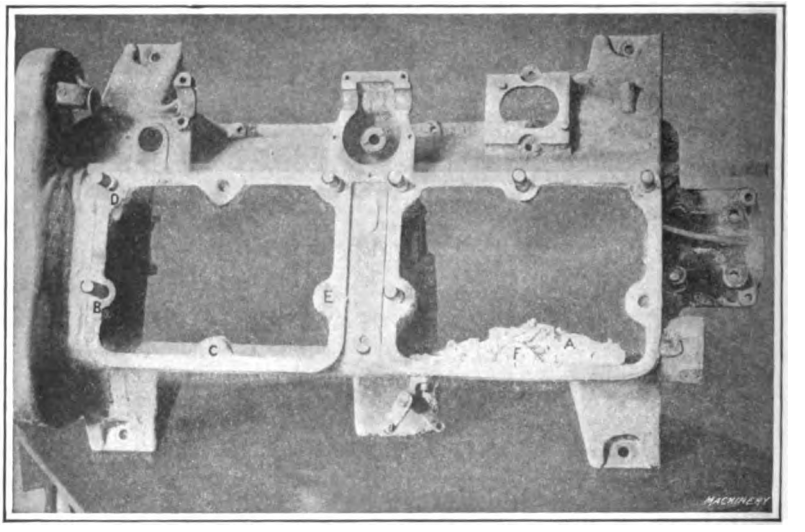



**Fig. 9. Aluminum Crankcase showing Method of Preventing Cracks in Welding**

strictly avoided; thus, if an alloy containing, say, 25 per cent of zinc, is being welded, its melting point will be approximately 90 degrees F. lower than that of the aluminum added, the result being increased difficulty in working and incoherency of the parts rather than a true autogenous weld. At the same time, if pure aluminum is used, the weld-zone will be softer and more flexible than the rest of the work. In addition, the weld-zone, if too soft, will be almost certain to break out again, and it is essential that the added metal should contain a percentage of zinc, so that the weld-zone will have a hardness approximately equal to that of the rest of the article. The conditions as stated should be observed

as nearly as possible, if a true autogenous weld is desired. It will be gathered from the foregoing that perfect welds are thus readily attained in aluminum and the aluminum-zinc alloys by those having adequate knowledge of how to employ this new art correctly.

**Difficulties in Welding Aluminum-zinc Alloys.** — A zinc alloy is generally identified by the condensation of the white zinc oxide on the cooler part of the casting during welding, and it may be necessary to cut or break the casting at some place where it can be repaired without bad contraction strains, in order that the weld in the original break may be made. It is not very often that the zinc alloy is encountered at the present

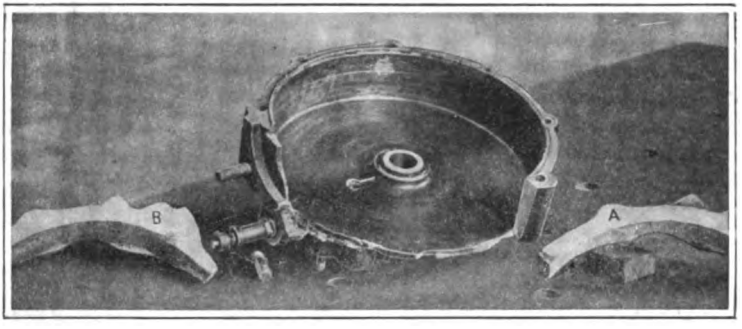



**Fig. 10. Aluminum Crankcase, Defective Part used for Pattern and New Part cast from Pattern**

time, although, when it is, it may cause the welder a great deal of trouble, and, in some cases, it may be impossible to do the work. It is necessary with such zinc alloys to preheat the whole piece to as high a temperature as is safe, and handle it very carefully. Sometimes it is advisable to have an extra man to help in handling the work, for if the piece is dropped or jarred it may be damaged considerably. When the weld is rather long, it is sometimes necessary to use two welders, beginning at the center and working toward both ends, so that the variation in temperature and the resulting strains are not so great as they would be if only one torch were used. In the case of a copper alloy, this brittleness does not exist to so great an extent, and it is not necessary to take such great precautions, but in all cases where

the defect extends into the body of the casting, it is advisable to thoroughly preheat and handle it carefully. Aluminum oxidizes readily, particularly at high temperatures, and as the oxide melts at a much higher temperature than the metal, and is heavier than the melted metal, it is likely to become mixed into the melted mass and produce a poor weld.

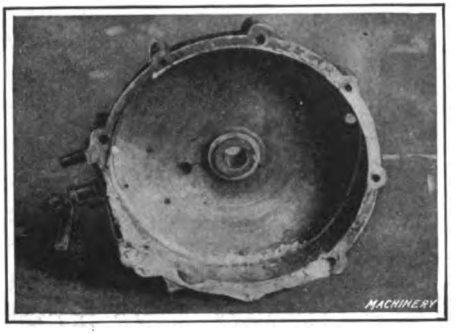



**Fig. 11. Same Crankcase as shown in Fig. 10 — Finished Weld on Inside**

**The Field of Aluminum Welding.** — One of the widest fields for the products of aluminum sheet welding is in the manufacture of large metal vats and utensils for brewing and industrial purposes. Compared with copper, aluminum sheets are now (1916) cheaper, 66 per cent lighter, and less readily attacked by organic acids. Any compounds formed with aluminum are absolutely non-poisonous and the metal is very easily cleaned. By welding and hammering the joints, the walls of brewing vessels are made absolutely flush without any projections. Brewing vessels are constructed up to 25,000 gallons' capacity, using aluminum plates up to 84 inches or more in width, shaped upon bending rolls.

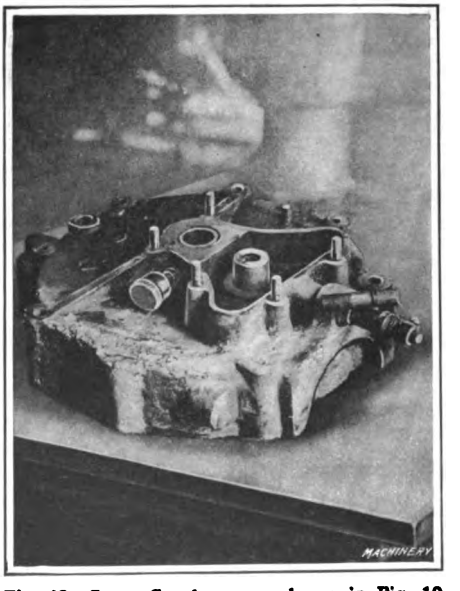



**Fig. 12. Same Crankcase as shown in Fig. 10 — Finished Weld on Outside**

The majority of these large vessels are cylindrical or spherical, but rectangular vats are widely used, many of these being of wood, lined with sheet aluminum welded in the form of the tank. Welding is also necessary for the production of tubular distillation coils; as tubing (particularly in the larger sizes) can only be drawn in limited lengths, it is necessary to join up a large number of pieces to form a tubular coil of average dimensions.

A further important use which is made of the oxy-acetylene torch is for the welding of automobile bodies. Many of these, particularly of the limousine type, are built up of aluminum sheets, the sheets being welded so as to secure an absolutely flush surface. This, however, is only one of the many promising fields for the autogenous welding of aluminum.

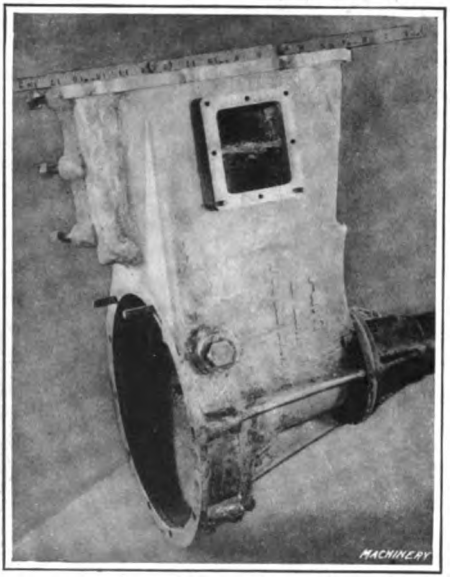



**Fig. 13. Example of Badly Damaged Aluminum Casting which has been welded**

**Examples of Aluminum Welding.** — Fig. 6 shows the best method of replacing a broken lug on an aluminum manifold. It should be laid on the table as shown, and a small weight put against the lug to keep it from moving. No larger tip should be used than is absolutely necessary, in order to avoid melting the lug, this being likely to occur if care is not taken. The cold table will tend to overcome part of this trouble, as it conducts an excess of heat away. After the back of the lug is welded (and the weld should be made almost entirely through from this side), the inside should be finished, being careful to remove all the crack.

It is not possible in the case of lugs on aluminum manifolds to use the block and clamps used in the case of cast iron, as alu-

minum would crush under the clamping strain. Immediately after welding, the lug should be tested with a straightedge to be sure that it is true with the rest of the face. If not, it can either be bent down, or a little metal added where it is low. In the majority of cases, and especially in the case of small lugs, it does not pay to put back the old lug, and it is good practice to build up a new one. An expert welder can build up a lug without any assistance from forms, etc., but the beginner had better make a mold out of a thin piece of sheet metal, of the height and shape of the lug, and hold it in place with a small weight, filling up the mold. The body of the manifold should be raised about $\frac{1}{32}$ inch from the table with a piece of a hacksaw blade, or something similar, to allow stock for finishing. It is necessary in this case to be particularly careful to secure a good union between the new metal and the old.

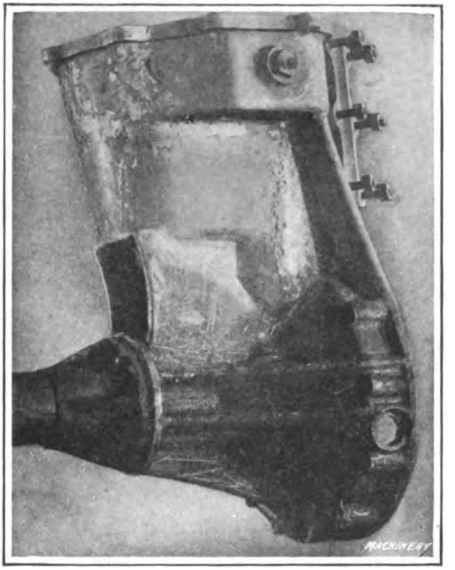


**Fig. 14. Opposite Side of Aluminum Casting shown in Fig. 13**

**Repairing an Inlet Manifold.** — Figs. 7 and 8 show the best method for repairing an inlet manifold. The original manifold was cast in one piece of aluminum. Later it was desired to change the carburetor, and, as the new carburetor flange would not fit the manifold, a new flange was made of brass and screwed on. The threads on the manifold can be seen distinctly. The repair was made by casting a flange of aluminum, using the old brass flange as a pattern by filling up in places to permit its being drawn from the sand, and welding it on. The finished job is shown in Fig. 8.

**Replacing Crankcase Lugs.** — Fig. 9 shows a type of crankcase that frequently gives trouble from the lugs breaking off. Here three of the lugs were broken when the case was received, and the shop was instructed to reinforce the others. The missing lugs were *C*, *E*, and *F*. These were built up solid. All the others were reinforced with the exception of *B*. This was not done because of the desirability, found by experience, of avoid-

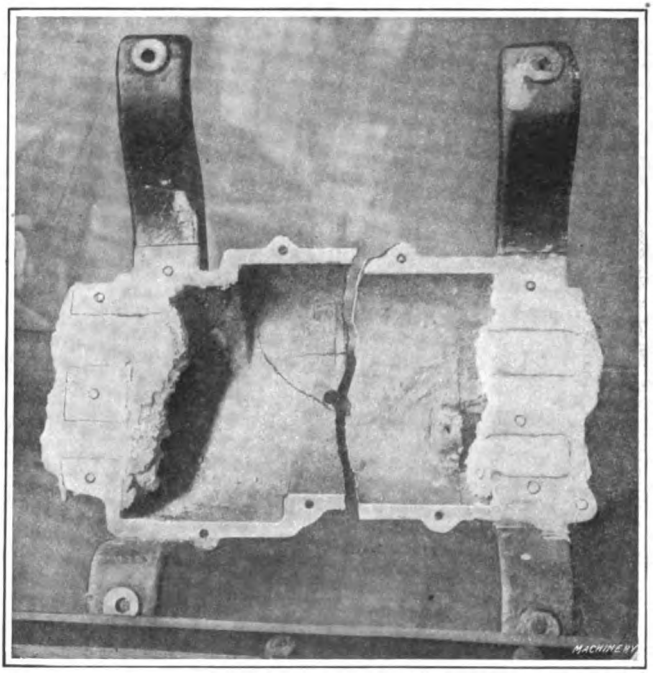


**Fig. 15. Broken Aluminum Transmission Case**

ing cracking through the end of the case, which generally happens, and, inasmuch as all of the other lugs for both pairs of cylinders were heavy, it was thought unnecessary to reinforce lug *B*. No precaution with which the author is acquainted will invariably stop the cracking at this lug. However, in the majority of cases, the welding of the lugs at *C*, *F*, etc., can be done without cracking the sides, provided loose wet asbestos, as shown at *A*, is packed so as to cover the side, and is allowed to become

dry while the case is preheating. This keeps the heat of the welding flame from striking the side of the case and overheating it. It should also be stated that, in the majority of cases of this kind, the material appears to be a zinc alloy, which is very likely to crack even with the best treatment. The foregoing

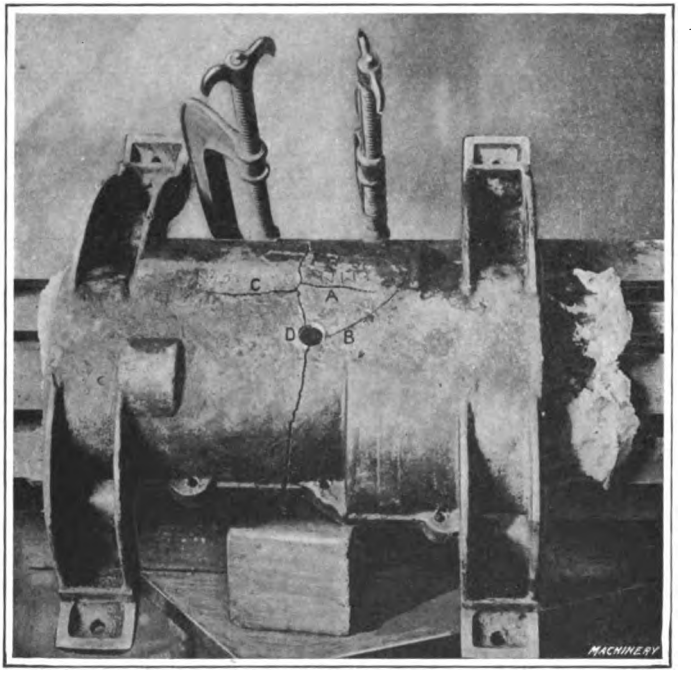



**Fig. 16. Method of Saving Bearings and Aligning Parts of Broken Case**

method of overcoming the difficulty can be frequently applied to other cases.

**Repairing a Crankcase.** — Figs. 10, 11, and 12 show an aluminum crankcase of an old-style automobile motor, which is located on the rear axle of the car. The part removed had been at some time soldered in, and while this job was all right for a while, it eventually began to leak. Another crack also appeared which made it necessary to repair it in some way. As it would have been impossible to do any welding in the presence of the solder, the entire defective piece was cut out and used as a

pattern, as shown at *A*, Fig. 10. Enough plaster-of-paris was added on the inside and face of the piece to allow for finishing. The casting made from the pattern is shown at *B*, and the finished work in Figs. 11 and 12. This job illustrates the possibility of using the pieces removed as patterns, instead of making new plaster-of-paris patterns. Even when the parts removed are quite badly broken, they can sometimes be fastened together

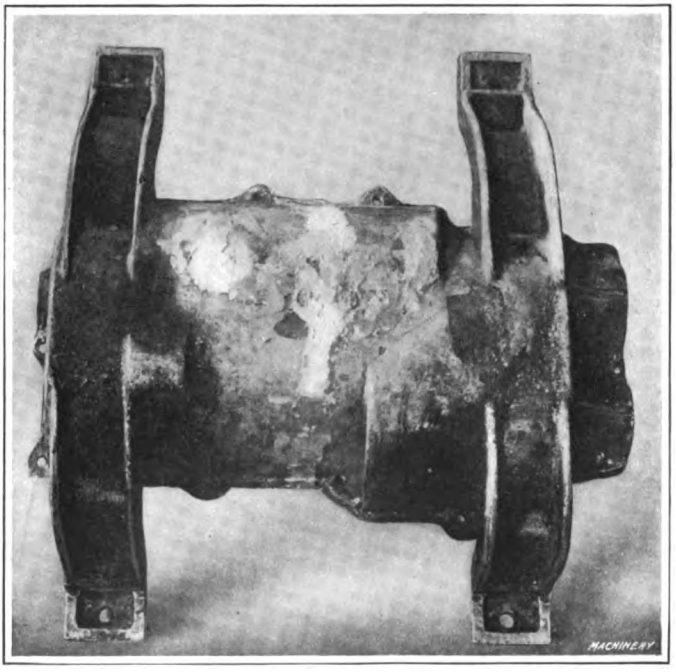


**Fig. 17. Outside View of Completed Repair Job**

with plaster-of-paris much more easily than a new pattern could be made. This is particularly true where there are lugs or other projections which are difficult to reproduce in plaster-of-paris. A little ingenuity will frequently reduce the time on a job of this kind considerably.

**Repairing an Aluminum Housing.** — Figs. 13 and 14 illustrate what can be done with a badly damaged aluminum casting. The process through which it was put is no different from that

which has been explained before, and is of interest principally on account of the fact that there was over six feet of cracks in the piece. In this particular case, the preheating was done with two Bunsen burners which were kept lit while the piece was being welded. The Bunsen burners were used on account of the difficulty of handling the piece in the fire. While it is generally unnecessary to use a helper to handle a piece of this size, in this

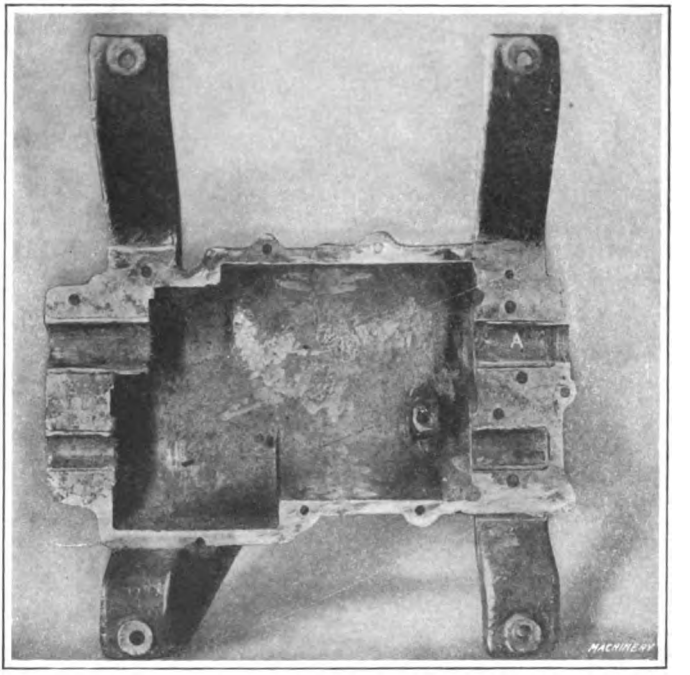



**Fig. 18. Inside View of Welded Case**

case, on account of the location of the breaks and the large number of times the work had to be turned over, time was saved by using a helper.

**Repairing Aluminum Transmission Case.** — Figs. 15 to 18 show a badly broken aluminum transmission case of an old design with babbitt bearings. It is quite difficult to re-babbitt such bearings so as to preserve the center distances between the shafts, unless a jig is available; hence it was decided to

save them. The width of the face of the crankshaft jig was just right to permit of the face of the transmission case being laid on it and clamped in position as shown in Fig. 16. This does not show, however, all the clamps that were applied. The two clamps shown are simply to hold the pieces in place while the photograph was taken. The first operation was to weld

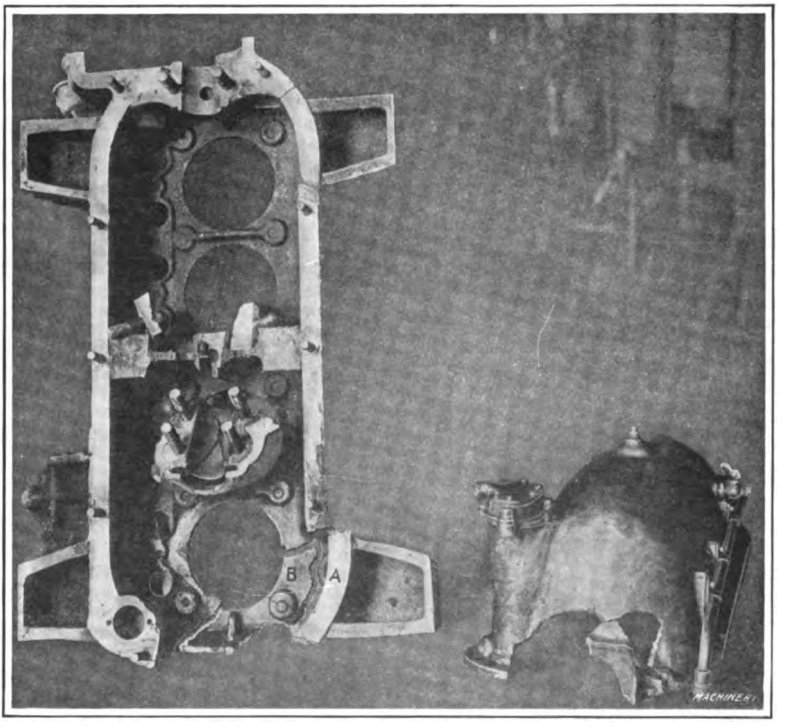



**Fig. 19. Upper and Lower Halves of Crankcase as received for Repairs**

the cracks *A*, *B*, and *C* while the two halves were separated. The case was then lined up, and, in order to prevent uneven contraction, two welders did the work, beginning at the hole *D* in the center. When the first man had welded about 2 inches on his side, the other man started in, and they finished the case together. The result was complete alignment and a very satisfactory job. The finished work is shown in Figs. 17 and 18, after it had been rough-ground. In order to save the bearings, they

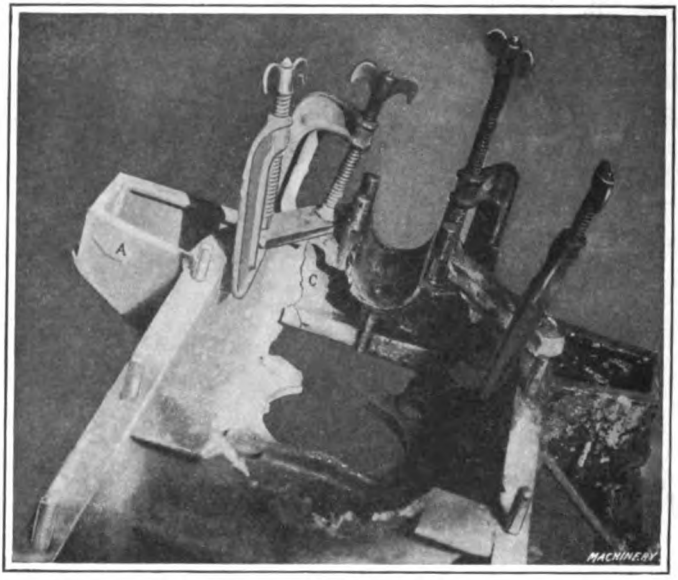



**Fig. 20. Method of Clamping Broken Bearing in Place**

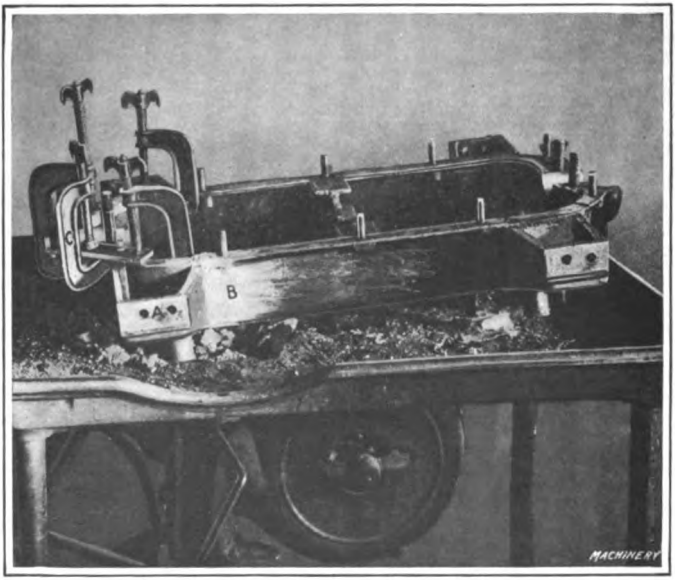



**Fig. 21. Aluminum Crankcase being reheated**

were filled with plaster-of-paris as shown in Fig. 15. This was allowed to dry thoroughly, and was then warmed over a gentle charcoal fire to drive out the moisture. The plaster-of-paris was scraped off level with the face of the aluminum, in order that the cold base of the crankshaft jig might come into as close contact as possible with the babbitt and thus keep it cool while welding. Preheating was done with two Bunsen burners, one on each side. All the babbitt was saved, except the small corner in one

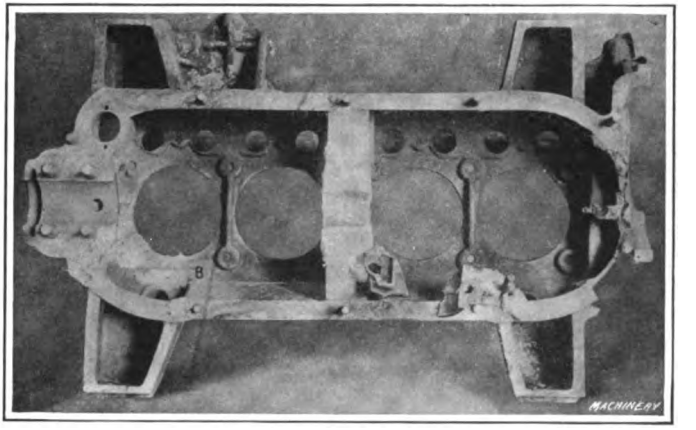



**Fig. 22. End Bearing finished, Center Bearing built up, and Front Bolting Lug welded**

bearing, as shown in Fig. 18, at *A*. The alignment of the bearings and face was perfect.

**Repairing Badly Damaged Crankcase.** — Figs. 19 to 28 show that, no matter how bad the damage may appear, it is possible to repair a crankcase, provided a little ingenuity is used. One of the frame lugs is entirely broken off and another cracked on both sides, and all three bearings are broken out; in addition, most of the end of the bottom half is missing. This damage was caused by allowing the center bearing to become loose, which caused the crankshaft to break and resulted in the damage shown. An examination of the crankcase made it evident that it would be very difficult and inadvisable to replace the pieces of the center and front-end bearings. At the time Fig. 19 was photographed, it was not noticed that the top-end bearing was

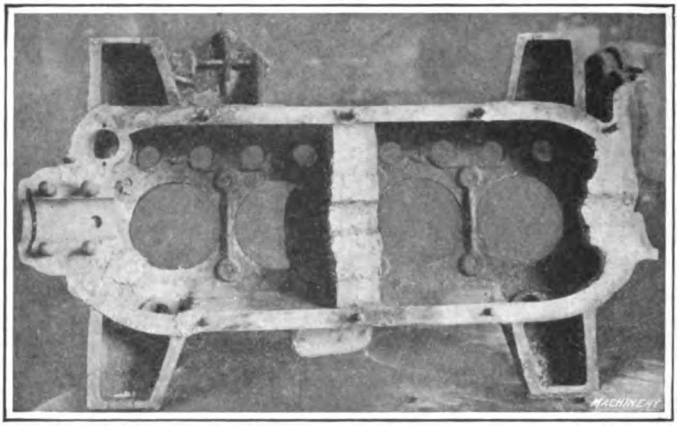


Fig. 23. Upper Half of Crankcase as shown in Fig. 22, with welding completed

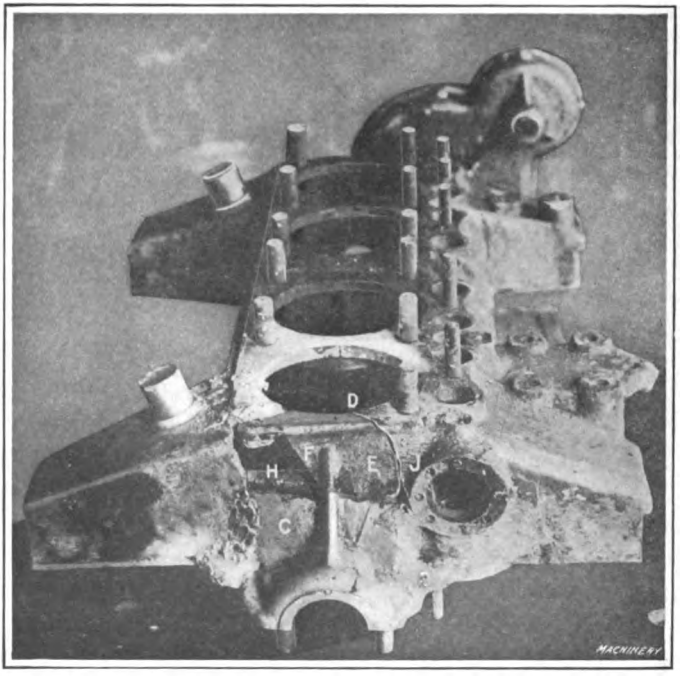



Fig. 24. End Bearing partly welded in and Pieces set ready for Welding

as badly broken as shown in Fig. 22, although it was known to be cracked. The first operation was to warm the crankcase in a rather small charcoal fire, as shown in Fig. 21, and weld the frame lug *A*, Figs. 19, 20, and 21, in place, taking care to put it in line as closely as possible. This weld is shown at *B*, Figs. 21 and 22. The next operation was to set the rear-end bearing *C*, Figs. 20, 21, and 24, in place, clamping it as shown in Figs. 20 and 21. Planed blocks were used to hold it true, the surfaces of the body of the crankcase on which these blocks rest having been previously tested with a straightedge to make sure that they were true. It is generally desirable in the case of a crack in the side or end of a crankcase to do all the welding except one crack, and then begin with one end of that crack, as for instance at *D*, Fig. 24, and end up at the other end.

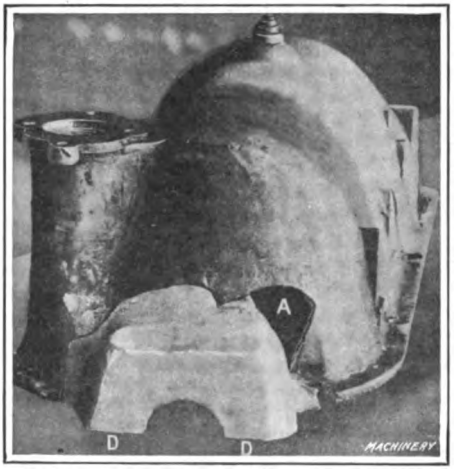



**Fig. 25. Lower Half of Crankcase to be repaired**

**Fig. 26. Plaster-of-paris Pattern for Missing Part and Rear-end Bearing Cap**

In this case, this is not advisable, because the important point is to have the rear-end bearing accurately in position, and this can be done better by setting the fractures

together, than would have been possible if any shrinkage had taken place from the prior welding-in of piece *E* and filling up at *F*, Fig. 24, which latter part was missing. It is evident that it would have been difficult to make the bearing straight and true under these conditions.

In Fig. 24, when welding in the end bearing, the two side welds were not finished quite up to the ends of the breaks at *H* and *J*. This was to permit of an easier fitting of the piece *E*, and is a practice that should also be followed where several pieces have to be put in separately. It might be stated that the end bearing fitted in place very nicely, as may be seen from Fig. 20. Piece *E* was then welded and hole *F* filled up, as was also a stud hole in boss *B*, Fig. 19. It is not advisable generally to attempt to preserve the thread in a hole through which a crack runs. The job is much more solid if it is filled up. The next operation was the welding of the center bearing, which, as explained above, was built up new. Then the other frame lug was welded as shown in Fig. 22, and finally the front-end bearing was built up, the finished job being shown in Fig. 23.

**Fig. 27. Lower Half of Crankcase shown in Fig. 25, as repaired**

Some knowledge of the shape of the rear end of the bottom half of the crankcase was needed in order to make the pattern shown in Fig. 25. It so happened that the welders were familiar with what had to be done, or it would have been necessary to examine a similar part in good condition. The bearing cap was put in place on the upper half of the crankcase and used as a guide in the preparation of the pattern. It was necessary to remove that part of the pattern which occupied the space *A*,

Fig. 25, as, if it had been left, it could not have been drawn out of the sand. Stock was allowed for finishing at *D*, Fig. 25, and *B* and *C*, Fig. 26.

Figs. 27 and 28 show the lower half of the crankcase welded, while Fig. 29 shows both halves of the crankcase machined and ready for service, except for the drilling and tapping of the holes for the center and front-end bearing cap studs. This could not be done, as the caps were not at hand.

No special precautions had to be observed in welding this case, the main considerations being the measuring of the diameters of the bearings before doing the work, as no two of them

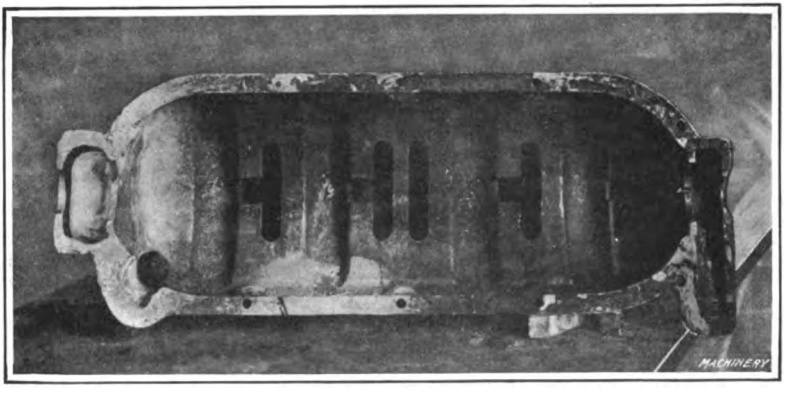



**Fig. 28. Inside View of Repaired Lower Half of Crankcase**

are the same size; keeping the crankcase quite warm while doing the work; and doing it as quickly as possible, which is a necessity in all aluminum welding. Of course, the machining of such a job requires considerable care and is best done, as far as the bearings are concerned, in a horizontal boring machine. If this tool is not at hand, it can be done in a lathe by clamping the case on the carriage and using a boring-bar between the centers. The job can be done in one-half the time or less on a horizontal boring machine, as it can be set up with greater ease and accuracy. The cylinder face of the upper half was milled off at the weld, but it was not found necessary to bore the rear-end bearing, nor to mill off any of the faces of the crankcase, except where stock

had been allowed for the purpose, or where the welds had been made; so that it is perfectly possible, by taking due care, to avoid much of the machine work that is frequently done.

This example of welding is given in considerable detail, because it covers a great number of instances which do not have all of the different kinds of damage sustained by this one. It was

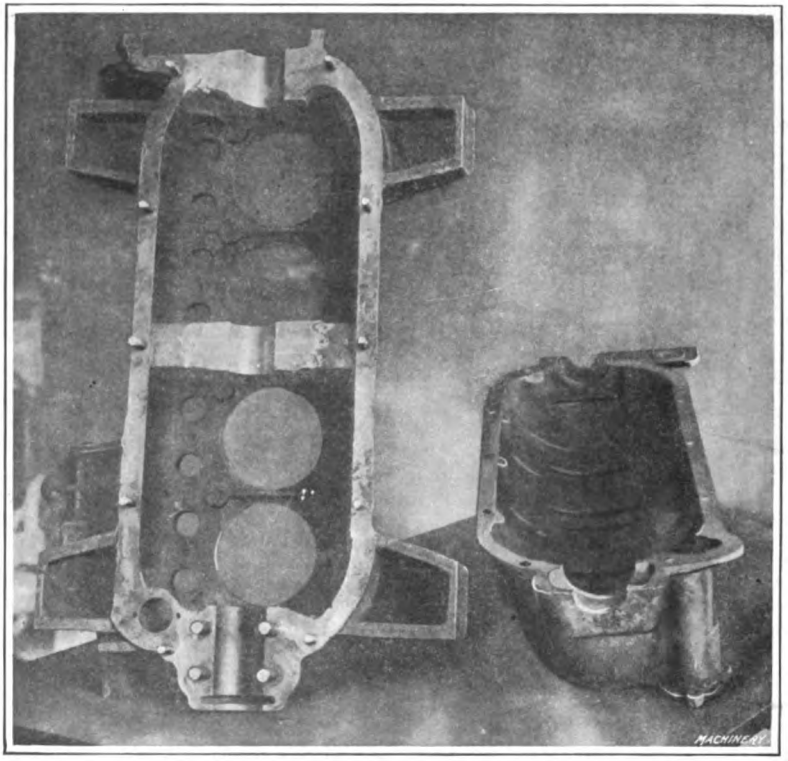



**Fig. 29. Both Halves of Crankcase Machined and Ready for Assembling**

not a particularly difficult job, although considerable time was consumed in doing it. The comparative simplicity is largely accounted for by the fact that there was no trouble from contraction, the damage being so great that the strains were easily taken care of.

**Aluminum Castings for Repair Work.** — It might be well to mention here the necessity of obtaining good castings for such

repair work. It will not do to use the material frequently furnished by small foundries, which they claim to be aluminum. The author uses nothing but No. 12 metal, which can be purchased from aluminum manufacturers in pigs. No scrap whatever is permitted, nor any other alloy. In case of serious difficulty in obtaining castings of the proper quality, or if it should be necessary to send a long distance for them, it is recommended that a small crucible be obtained and pig metal melted in it in a small furnace designed for the purpose. This furnace can be connected with any flue ordinarily used in a stove. It is not satisfactory to melt this metal in an iron ladle, as it is too much exposed to the action of the air. As soon as the metal is melted, it should be covered with a layer of fine charcoal to prevent oxidation as much as possible. A small flask made of wood and some fine molding sand are easily obtained, and will be found very convenient for many purposes.

Care should be taken in melting aluminum not to allow it to become too hot, and it should be well skimmed while pouring to prevent the oxide from passing into the mold. The shrinkage of aluminum is considerable, about $\frac{7}{32}$ inch per foot, and the pattern should be well rapped in order to allow for this, or else the necessary stock should be added to the pattern to take care of it. A beginner will probably have some trouble at the start, but a little care, and if possible, the observation of the various processes at some foundry, will help a great deal. A greater amount of pig metal should be melted than is needed for the casting, and any surplus should be poured into a mold or into a hollow made in the sand pile, and not left in the crucible.

## CHAPTER VIII

### SHEET METAL, BOILER, PIPE, AND TUBE WELDING

SHEET metal is used in so many different forms and for such a variety of purposes that it is impossible to give any specific directions that will cover all cases, in regard to the methods to be followed in welding it. However, some general points can be noted, and the application to specific cases can often be derived from them. It should never be forgotten that in any welded piece there are strains due to contraction and expansion caused by the heating. In the case of brittle metals, such as cast iron, this strain will probably manifest itself by the piece cracking at some time during the operation or afterward. In the case of tougher metals, such as steel, the strain may not and probably will not so manifest itself, but it will be found instead that the piece will become distorted. The same general principles for taking care of strains in brittle metals apply in the case of tough metals. In other words, contraction must be allowed for in some way, either by preheating, separating the parts, or by expanding some part of the piece by heat or power, etc.

**Warping due to Heating of Plates.** — If a piece of steel plate $\frac{1}{8}$ inch thick and 6 inches square be heated red-hot in the center with a torch, no particular change will be noticed during the heating, but on cooling off, while no crack will occur as it would if the plate were made from cast iron, the sheet will become badly warped. This warping can be remedied, as is done in everyday practice in boiler or tank shops, by laying the plate on an anvil or solid block of iron and peening it with a hammer until it is straight. This is an operation that requires considerable skill and experience, and is brought to its highest development in the case of large circular and band saws used for cutting wood. These have to be "hammered" to suit the speed at which they run and the conditions under which they operate.

Without some experience, an attempt to straighten such a piece of steel will result in making it worse than it was originally, and while this process can be used, it is desirable to avoid it, if possible. In the case of a small sheet, much of the difficulty can be overcome by heating it red-hot before welding, but, in the case of a large sheet, this practice is not feasible, and it is generally difficult, if not impossible, to weld it neatly at the center. However, it is seldom necessary to make such an attempt, the majority of sheet welding being done along the edges, or in other places where the expansion due to the heating can be more readily controlled.

**Welding Thin Sheet Steel.** — The welding together of short pieces of thin steel may be frequently accomplished by preheating the whole piece along the edges to be welded. If there are many pieces of one kind to do, it will pay to make an arrangement by which a gas burner can be kept under the weld while it is made. In such cases, the weld may be "tacked" (joined by an autogenous spot weld) at several points along the edges, and if it is kept red-hot by the gas flame it will give very little trouble, and in many cases the distortion will not be sufficient to cause any difficulty. On the other hand, in repair shops, it is not often that many pieces of one kind are done, it being generally odd jobs that are received. In cases where the weld is long, the best plan is to separate the sheets at one end by an amount equal to about $2\frac{1}{2}$ per cent of their length, and bring them together at the other end. If it is found that the contraction of the weld pulls the sheets together too fast, it will be necessary to hold them apart by clamping, wedging, or some other method, forcing the contraction to take place in the weld rather than allowing the sheets to be pulled together. If, on the other hand, the sheets do not come together fast enough, stopping the welding process for a short time will generally correct the trouble, as the sheets cool off and do not again regain the same amount of heat.

It is not possible to clamp thin sheets so tightly that the edges may be brought absolutely together and all the contraction forced to take place in the weld. Even with very powerful

clamps it is practically impossible to obtain the same pressure at all points along the edges, and where the pressure is less, the contraction will be greater, the result being a buckling of the sheet and a wavy appearance on finishing the job. One of the easiest ways on odd jobs of this kind is to put a cross of $\frac{1}{2}$-inch round metal between the sheets a considerable distance ahead of the torch, advancing it or moving it back from time to time as the contraction of the weld warrants. This has its limitations, because, when the sheet is very thin, it will bend rather than force the contraction to take place in the weld; but if the sheets are $\frac{1}{4}$ inch thick or more, it is very satisfactory, particularly if clamps are placed across the sheet in several places, to keep the edges in line vertically. Another objection to the use of clamps is that, unless carefully designed, it is impossible to obtain the same pressure on the sheets twice in succession, and if it is found that a certain pressure with a certain amount of opening at one end will answer the purpose, it is evident that less pressure will cause the sheets to come together too fast, and *vice versa*.

In the case of very thin material, such as is used for steel doors in railway passenger equipment, many ingenious jigs and clamps have been devised to hold the parts absolutely in line while welding. They all operate on the principle of forcing the contraction to take place in the weld. As they are special for each type of door manufactured, and as they are too expensive and generally not applicable for repair welding shops, no attempt is made to give any details of their construction, it being sufficient to say that the results obtained by their use are exceedingly satisfactory, and good results could not be obtained without them.

The methods outlined are applicable not only to flat sheets, but also to longitudinal seams of tanks such as range boilers, oil barrels, etc. In many cases, automatic welding machines have displaced hand work on such articles and give a regularity of welding, uniform quality and appearance that is not obtained by hand welding. Light sheet welding by hand is really a special trade. The welder must have a steady hand and must keep in continual practice. While such welds made by an ordinary

welder would appear to him very regular and uniform, they would seem to the expert sheet welder rather rough and irregular, although they might be perfectly sound. Such welds, if properly made, require very little finishing and result in as smooth a surface after grinding as the original sheet, and also have no buckling or other defects. The thicker the sheet is, the less is the trouble from buckling, and it is generally possible to make a nice appearing and sound weld in such sheets by keeping the wedge of metal between the sheets some distance ahead of the torch, as previously explained.

**Speed of Sheet and Plate Welding.** — The following table shows the speed at which the welding of steel and iron plates can be carried out, and also the approximate acetylene consumption; this table is furnished by the Davis-Bournonville Co.

| Thickness of Metal, Inch | Feet Welded Per Hour | Acetylene, Per Hour, Cubic Feet | Thickness of Metal, Inch | Feet Welded Per Hour | Acetylene, Per Hour, Cubic Feet |
|---|---|---|---|---|---|
| 1/32 | 30 | 3.25 | 5/16 | 9 | 18 |
| 1/16 | 25 | 5.00 | 1/4 | 6 | 25 |
| 3/32 | 20 | 8.25 | 3/8 | 4 | 42 |
| 1/8 | 15 | 12.00 | 1/2 | 3 | 60 |

The oxygen consumption will be 1.1 to 1.5 times the acetylene consumption, depending upon the quality of the blowpipe employed. As would be expected, the gas consumption per foot of work increases more rapidly than the thickness for all except the very thinnest material, and the speed at which the work can be done decreases in about the same ratio as the thickness increases. On the basis of the figures given in the table, it has been stated that, for constructional work, $\frac{3}{8}$-inch metal is about as thick as should be worked with the oxy-acetylene welding method, except in cases where older methods, such as riveting, are impossible. For repair work, the case is altogether different; metal of any thickness can be worked, and, in almost all cases, the repairs effected will be made more quickly, better, and more economically, than by the older methods. As regards constructional work, the conclusion that a $\frac{3}{8}$-inch thickness constitutes the limit of the metal that can be economically

welded is somewhat too sweeping, however, as this depends entirely upon the conditions; and, at the present time, there is a great deal of new work done on sheets $\frac{5}{8}$ inch thick and over. The considerations which influence the selection of the method of joining thick sheets, aside from cost, are smoothness, tightness of the joint, the pressure to which the joint will be exposed in service, the stresses in the parts welded, and a number of other things suggested by the circumstances. These conditions all have an important bearing upon the selection of the method,

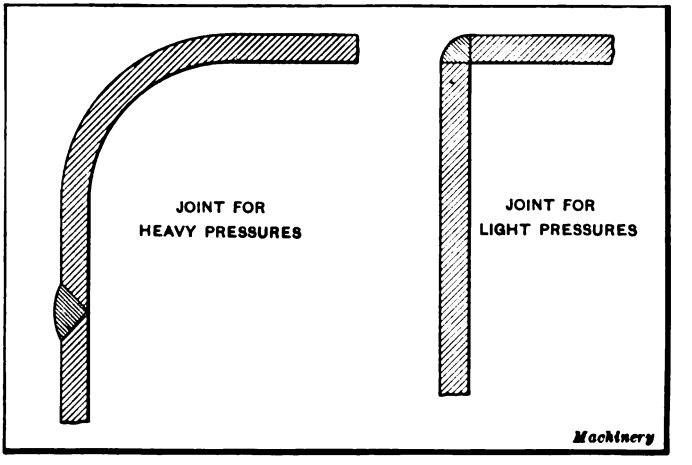



**Fig. 1. Methods of Making Joints for Heavy and Light Pressures**

and must be considered in repair work as well as in manufacturing.

**Welding Copper and Aluminum Sheets.** — The welding of sheets of flat metals other than steel is only done in exceptional cases, and, while the same principles apply, other metals are generally more ductile, and the strain can be more readily taken care of. It should not be forgotten that all such welds are castings, and, except in the case of aluminum, the weld will not be as strong, nor can it be hammered or otherwise worked as safely as the original sheet. Pure rolled sheet aluminum or aluminum sheet with but little alloy can be welded with excellent results, if a satisfactory flux is used, and the resulting weld

will be as malleable as the original sheet. Such work is done every day in the case of carriage and automobile bodies, and the metal is afterward beaten over the forms without any difficulty. In the case of copper and brass, proper annealing will help the brittleness of the weld very much, but this cannot always be done, and, therefore, care should be exercised in subjecting the weld to hammering, rolling, etc.

**Welding Heads of Tanks.** — In the manufacture of steel tanks, there is no special difficulty in welding in the heads. There are, however, a number of precautions that should be observed in the preparation of the pieces, the principal one of which is that they should be so designed as to avoid anything except tensile strain in the weld; that is, no design should be made in which there is any chance of a bending strain occurring, due to internal or external pressure. When the pressure is very low, this rule may, of course, be disregarded. Two examples are given in Fig. 1, showing good construction, and, as these are economical as well as safe, it is not necessary to show examples of objectionable ones, it being safe to assume that constructions other than those shown will not give as good results. There are two principles to be followed in making such joints: 1. That the included angle of the V should be at least 90 degrees. 2. That the sum of the edges of the V should be as short as possible. Modifications of these principles may be allowable in special cases, but, for all ordinary work, they should be strictly followed. In making any welds in tanks subjected to pressure, care must be taken to have the weld made entirely through the sheet, so that there is no crack or remnant of the original edges of the sheet left unjoined. This subject is treated in greater detail in the next chapter.

**Boiler Welding.** — The welding of boiler sheets is a specialty, and should not, except in the simplest cases, be undertaken by a repair shop, unless the welder or the person in charge is thoroughly familiar with boiler construction and the ordinary repair methods. So much depends upon the soundness of a boiler that only the very best work is justifiable. Such work can only be obtained from a thoroughly honest, competent welder, who will

at all times do the best that lies in his power. Sound welds, free from burnt and oxidized spots and slag, cannot be obtained, even by the best welder, without a good torch. It is also almost necessary that the person in charge of the shop be familiar with boiler construction and repairs.

For these reasons, Henry Cave has proposed what he calls the "three license system," for boiler welding, by which the proper authorities would license the plant doing the work, the apparatus to be used, and the men actually doing the work after proper examinations and tests had been made. There is much to commend this plan, although the details would have to be worked out carefully. It would appear that if those in charge of the operation of boilers are compelled to obtain a license for the protection of the public, those making repairs should also be compelled to adopt similar "safety-first" methods. The author believes that, in addition, the moral character of the welder should be carefully looked into, as all the welder's faculties must be on the alert.

For such shops as are equipped to do this kind of work, the rules of the Federal government in connection with marine inspection are an excellent guide as to what may be undertaken in the present state of the art. These rules are, of course, conservative and, in the case of marine work, must be closely followed. The Federal rules are given in the "General Rules and Regulations prescribed by the Board of Supervising Inspectors," copies of which may be obtained at any of the local offices of the Inspection Department, or from the Department of Commerce at Washington, D.C.

The boiler insurance companies must be consulted about the work contemplated in all cases when insurance is carried, as their inspectors would reject it unless the work met with their approval, and the insurance would lapse. As a matter of self-protection, a repair shop should be cautious about boiler welding, because if anything happened later to the boiler, even though it were not the fault of the welding, serious injury might result to the reputation of the shop doing the work. On the continent of Europe, much greater progress has been made in the welding

of boilers than in the United States, and much work is done there that is not yet permitted here. Hence, there is a vast field open to those who are willing to take the time and make the effort to become accomplished welders in this line.

The technique of boiler welding, except in the case of a few specialists, is not yet developed to the point where anyone except such specialists should make welds in sheets where the working stress is entirely tensile, such as the shell of any boiler or the roof sheet of a locomotive type boiler. The Interstate Commerce Commission prohibits such welding in locomotive boilers and with good reason, as a defective weld in such a location would, in all probability, result disastrously. Nothing about a boiler should be welded unless the result will be perfectly safe.

There is probably no other important mechanical structure in which more accurate knowledge exists as to the actual stresses involved, and as to the strength of the various joints used, than a boiler. This knowledge, however, is unfortunately not as widely disseminated as it should be, and the lack of it (and in some cases the desire to build boilers as cheaply as possible) has resulted in construction that is not good and is sometimes dangerous. These cases are not so common as they used to be, with the result that modern boilers generally give little trouble from defects, unless they are badly treated, or carelessly repaired. The chance of being called on to make repairs to a boiler, therefore, is generally in the case of one that is rather old. Under these conditions, the author always makes a careful examination and if he thinks the boiler is unsafe, he refuses to do any welding at all on it. It is a safe plan for the owner of a defective boiler to have it inspected by one of the boiler insurance companies; and if they will insure it after the welding is done, of course the work can be proceeded with. If they will not insure it, the repairs should not be done.

**Simple Boiler Repairs.** — There are a number of simple boiler repairs that can be readily made, in which the strength of the boiler is not particularly involved, such as welding flue-sheet bridges, fire cracks in seams from the rivet holes to the edge

of the sheet, etc. In all cases, a V should be made entirely through the sheet, leaving the bottom of the V open at least $\frac{1}{16}$ inch, so that the metal can be welded from the bottom up. The dirt and scale should be well cleaned off the inside of the sheet as well as the outside. It should not be forgotten that lime or any similar form of scale tends to make a brittle weld. Where one sheet laps over another, as in the case of a fire crack in a seam, the edges of the crack should be raised after beveling by heating somewhat with the torch and driving a chisel underneath. This permits of the weld being made entirely through the sheet. In taking care of the contraction after such work, great reliance can be placed on hammering of the weld just after it is made so as to expand it. The hammering must not be continued too long, that is, below a blue heat, or the tendency will be to produce a crack.

Fire cracks and broken flue-sheet bridges mean short welds, and there is very little chance of leaving a strain in those cases. Where the weld is longer, much judgment must be used in hammering, to avoid producing serious strains which may later result in cracking the sheet. Again, there are cases where sheets are corroded in spots. These can generally be built up with perfect safety and to good advantage. Frequently an expensive replacement may be avoided by doing this. However, in such cases, there will undoubtedly be a loosening of the rivets if there are any in the vicinity of the work, and these will have to be replaced or calked to overcome leaks. In some cases, it pays to cut out the rivets and redrive them after the welding is done. Another frequent and rather easy repair is the adding of sufficient metal to a worn calking edge to permit of the sheet being recalked. This can easily be done without welding to the sheet underneath. After the welding is done, the metal may be hammered down and chipped and calked as in the original construction. A small patch can be applied in the corner of a firebox quite readily, but the rivets should be removed for a distance of 8 or 10 inches to allow for contraction.

In a general way, there is but little difficulty from contraction in welding where there is a change of direction in the sur-

face of the sheet, for example, near a flange or similar bend, because, by removing a few of the rivets, the contraction takes care of itself and the rivets can generally be replaced easily. However, in the case of a flat sheet, the problem is entirely different. The welding of cracks in boiler furnaces or fireboxes requires a high degree of skill and knowledge, and generally necessitates the use of special appliances for confining the heat to a narrow zone. Such cracks do not develop singly, but are accompanied by parallel cracks for quite a distance along the sheet. These are frequent in locomotive boilers, and are due to the fact that under severe service the water is driven away from the sheets so that they become overheated. When they are hot, the pressure in the boiler tends to bulge them, causing cracks to appear on the fire side between the vertical rows of staybolts, and on the water side through the centers of the staybolt holes. In the course of time, one of these cracks goes through and begins to leak. While there may be no evidence of any more cracks, the bulging of the sheet indicates that there are at least incipient cracks besides the one giving the trouble. Now if the leaky crack be welded, the shrinkage of the weld will open up one of the cracks somewhere in the vicinity, the weld being stronger than the rest of the sheets.

An instance has been cited where a large number of cracks of this kind were welded in one firebox, the result being that finally there was a considerable gap in the last crack that developed, this being approximately equal to the sum of the shrinkages of the welds. In such a case it may be possible to weld a crack, but the author does not believe it advisable except for temporary purposes, and then with the distinct understanding that the job is not sound and further trouble will undoubtedly result. In order to take care of the contraction, it is sometimes the practice to run streams of water or compressed air on the sheet on each side of the crack, about 4 inches from it, thus preventing, to a large extent, the expansion due to the heat of the torch and reducing the contraction.

The highest development of the welder's art is needed in the application of patches in the center of a stayed surface, such as

a side or flue-sheet of a locomotive firebox. There is no particular difficulty about welding the first side or even the second, but the trouble comes on the third and fourth, particularly on the last one. It is always necessary to use a box patch, that is, one that is dished in the center, so that the dishing will take the strain. Such work, as well as the application of entire side sheets, and patches 12 feet long in large fireboxes, are perfectly possible, and in fact are done every day in locomotive boiler shops, but they are the work of men who are trained in that direction, and they should never be done by any ordinary welding shop. It is, therefore, unnecessary to give any detailed description as to how this work should be attacked, particularly as the appliances for doing it are special, and have to be modified to suit each case. There is one thing, however, that should always be done in case of any work inside a boiler, or other confined space. An extra man should be stationed at the tanks, which should always be kept outside of the space or boiler, so that, in case the hose bursts and the acetylene catches fire, it can immediately be shut off, thus avoiding possible fatal injury to the men inside.

**Welding Galvanized Plates.** — In the welding of galvanized plates, several difficulties are met with. The flame in contact with the zinc-covered plate produces vapors and fumes of a nature which may seriously affect the health of the welder. The welds are also liable to contain impurities — zinc and slag — and as the soundness of the weld is directly dependent upon the amount of slag and zinc, it is, therefore, necessary to remove the zinc from the vicinity of the weld before welding. The zinc should be entirely removed for a distance of from 1 to $1\frac{1}{2}$ inch on either side of the central line of the weld, and as the zinc has penetrated the steel to some extent, some of the steel will have to be removed also. This preparation makes the cost of the weld higher, and is, therefore, often neglected, but a strong joint cannot be produced in any other way, and the effect on the workman's health is detrimental if the preparation is omitted. If the plates are thicker than $\frac{1}{8}$ inch, they should be beveled in order to produce a good weld. The welding-rod

should be of Swedish iron of suitable dimensions for the thickness of the plate to be welded.

**Welding Tin Plate.** — In the oxy-acetylene welding of tin plate, tin is not eliminated as a vapor or oxidized, as in the case of zinc-coated metal, but as the tin is absorbed by the iron, when the latter reaches a red heat, an iron-tin alloy is added to the molten mass of metal, and the weld consists of very large crystals separated by numerous fissures and cracks. It is, there-

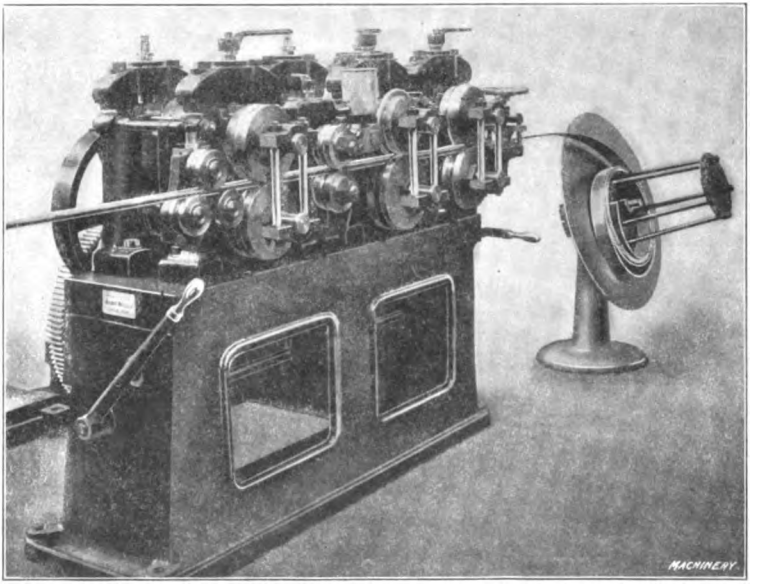



**Fig. 2. Tube-rolling Machine built by August Schmitz, Dusseldorf, Germany**

fore, impossible to weld tin plate with satisfactory results without first carefully removing the tin at the welding line and its immediate vicinity, in the same way as the zinc is removed from galvanized plates.

**Manufacture of Tubing by Autogenous Welding.** — The trend of industrial processes, to-day, is in the direction of continuity. If a process can be made continuous, a great advantage is gained, other things being equal. It is no wonder, then, that in consequence of the enormous demand for water, gas, and steam piping, very determined efforts have been made to produce tubing

by the process of rolling. The efforts have been successful, and steel tubing is now made in large quantities by this method. Strips of flat steel are rolled longitudinally between successive pairs of rolls until the edges meet or overlap. They are then butt- or lap-welded.

In Germany, tubing is made by the rolling of sheet metal and the subsequent welding with oxygen and acetylene, the process being continuous and a special welding machine being used. The rolling machine is of the type shown in Fig. 2. This machine receives the metal in long flat strips, which have either been specially rolled or cut to the required width. The first operation is accomplished by a pair of rolls which bend the longitudinal edges upward. These bent-up edges will ultimately form the "roof" of the tube. It is important that the degree of curvature of the bends shall be precisely that of the finished tube. Another pair of rolls just ahead receives the strip and bends it into a U-shaped form; the upper ends of the U-curve, however, are bent toward each other because of the side bends formed by the previous pair of rolls. Another pair of rolls is now employed to receive the U-shaped strip, causing it to approximate still more closely the tube-shape. Finally, another pair of rolls completes the bending to shape; a mandrel is employed with this pair. In case very elastic material is employed, it is advisable in the first pass to bend the axial portion so that when the tube is shaped it will point in toward the inside of the tube. In the last operation, this bend will be eliminated by the mandrel. The object is to obtain a joint with no tendency to open.

When a strip which has been cut from a sheet in the ordinary way is thus bent together, there will be a V-shaped groove along the joint. The reason for this is that the external circumference of an annular ring is longer than the internal one. The strip is of the same width on both sides, so that when one side is bent to form a complete inner circle there is not enough material for the outer circle. The weld can still be made, but, as machine welds use no additional metal, the section at the weld will be thinner than it ought to be. If the tubing is made of quite thin metal, no especial difficulty will arise from the formation of a

groove; but, when the wall is rather thick, strips which have been especially rolled to provide a greater width on one side than on the other should be used. When such a strip is bent to the final shape, there is a narrow V-shaped groove with ridges on each side. A narrow groove is advisable, because it admits the flame to the entire depth of the joint.

**The Tube Welding Machine.** — The welding machine is rather simple. Two pairs of compression rolls are placed a short distance apart, as indicated in the diagrammatical view, Fig. 3. These rolls carry the tube along, the one pair receiving it from the tube rolling mill. Between the two pairs of rolls a standard is placed to which is secured the device which holds the torch.

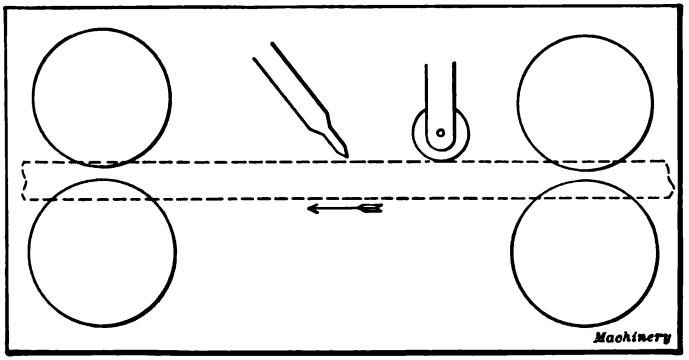



**Fig. 3. Principle of Autogenous Tube Welding Machine**

This latter has its tip directed downward and toward the unwelded joint. The angle of inclination is about 45 degrees. The tubing, as it is fed along by the first pair of rolls, cannot always be depended upon to keep its unwelded joint in a constantly uniform position. It is, however, necessary that the working flame of the torch and this joint shall be in an exact relation to each other. Therefore, a holder is provided which carries a roll or wheel having a thin edge or projection on its periphery. This edge enters into the groove at the joint and controls its position just before it reaches the torch. This machine is made of the duplex type, so that two welding operations may be handled at the same time; a torch and the necessary rolls are arranged on each

side of the bed. Comparatively thin tubing, say, 0.04 inch in thickness, can be welded at the rate of about 8 inches per second, or about 40 feet per minute.

**General Considerations in Tube Welding.** — It is frequently the custom in the bicycle industry to draw tubing to an oval or elliptical section. The most severe stresses to which such elliptical tubing is subjected would tend to injure the weld, if the latter should be located at the end of either axis of the ellipse. It has been found advisable, therefore, to locate the seam to one side of the "sharp" end of the ellipse. A Swedish charcoal iron, containing very little carbon, is claimed to be most suitable for this class of work.

In the rolling of tubes of small diameter, it is permissible to roll in a longitudinal direction, but with greater diameters, it becomes necessary, or at least advisable, to discard the continuous method and use rolls or other devices the axes of which are parallel with that of the tube. Machines specially built for this service bend the sheets quickly to the required cylindrical form. Diameters of from 3 to 10 inches are readily handled, the material having a thickness up to $\frac{1}{4}$ inch. The forming process requires from 7 to 12 minutes for each section of tubing, according to the length. Large tubes are usually welded autogenously by hand.

**Tests on Welded Tubing.** — That large pipe made by the oxy-acetylene process is reliable is indicated by the following test: Two sections of such pipe, each about 39 feet long and 35 inches inside diameter, had their flanges bolted together to form a single length of nearly 80 feet. The supports were placed at the ends so that the full length between them was unsupported. Then the double length of tubing was loaded with about thirty men, or, in other words, a load of more than two tons was supported. Of course this test does not take into account the question of the "water-tightness" of the weld. However, a test was carried out upon another piece of welded tubing — this time a bend — of about 2 feet inside diameter. The tube did not leak under a pressure of about 365 pounds per square inch. Another piece of tubing about 31 or 32 inches in diameter has been made by the welding process from material which was about 0.4 inch

thick. A drainage system for a lock of the Kaiser-Wilhelm canal contains about 2000 feet of pipe welded by the autogenous process. One German firm is manufacturing hot-water heaters by the same process.

**Acetylene Welding of Gas Pipe.** — George H. Manlove, in the *Iron Trade Review*, describes a method of making welded joints in steel and wrought-iron gas mains by means of the acetylene flame, which has taken the place of threaded joints and couplings. A skilled operator will produce unions the strength of which ranges from 80 to 95 per cent of the strength of the pipe, and by building up sections at the weld the strength is increased even beyond that of the pipe. Joints of this type permit great flexibility in construction and are claimed to assure absolute tightness. As far as possible the lengths of pipe are welded together outside the trench with a welding flame of a temperature of approximately 1650 degrees F. The metal on each side of the weld is fused and pure wrought iron is fused on the pipe to form a fusion weld. The limit of the number of sections which can be welded together before lowering into the trench is apparently limited only by city street traffic conditions and by the length of time which a trench can remain open. In the country, it is not unusual to weld as much as 1000 feet of pipe at one time, and, in one case, 4000 feet of 8-inch pipe were welded before placing in the trench.

After a section of pipe is welded, it is rolled into the trench and welded to the main already laid, a bell hole being dug to allow the operator to weld entirely around the joint. The longer the sections are made before the pipe is lowered into the trench, the fewer bell holes are necessary, and the more quickly will the work proceed. After a section of pipe is finished, it is capped at both ends and tested for leaks at any desired pressure. One of the advantages of this process is that lighter pipe may be used than where screw-joint couplings are used, as it is not necessary to allow any thickness of the pipe for threading. This results in a saving in cost, and in some parts of Europe it has been demonstrated that pipe of 40 per cent of the usual thickness may be utilized with the same results.

# CHAPTER IX

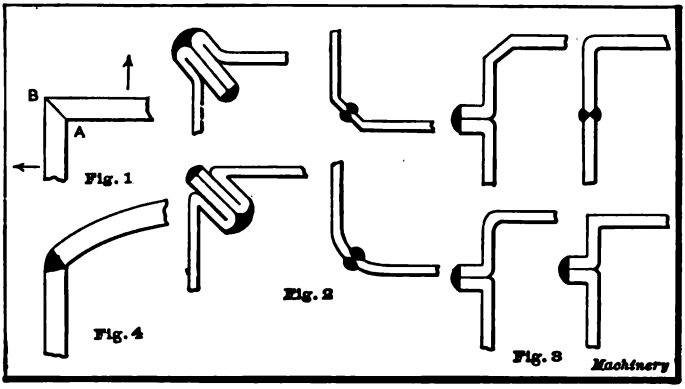
## OXY-ACETYLENE WELDING OF TANKS AND RETORTS

ONE of the most important applications of the oxy-acetylene welding process is in connection with the manufacture of tanks and cylinders from sheet metal. In this field, the new process promises to supersede soldering and riveting to a very large extent. The advantage over soldering consists principally in the increased strength of the joint and the equality of the expansion and contraction of the metal in the seam and in the work. There is also much less likelihood of the occurrence of poisonous corrosions.

**Form of Joint.** — In constructing vessels of sheet metal which are subjected to alternations of high and low internal pressures, it is generally advisable to use special forms of joints at the corners or to avoid corner joints entirely. The stresses on the corner joints become very severe, if the corners are of right-angled shape. If the corner is rounded, the effect of the internal pressure at the joint is reduced. In Fig. 1, for example, if the welded joint is made at the square corner $AB$, it will be located at the point where the stresses on it, acting as indicated by the arrows, will be most severe. By forming the joint in the various ways shown in Fig. 2, the weld will be considerably strengthened as compared with a weld that merely joins the two sides at the corner $AB$ in Fig. 1. It is still better, however, to remove the joint from the corner altogether. In Fig. 3 are shown the methods used for doing this. The best method of all to relieve the welds of the excessive corner stresses is to change the horizontal section to that of a circle.

**Tops and Bottoms of Sheet-metal Vessels.** — One of the most difficult operations in the welding of tanks and retorts is the attaching of the tops and bottoms to cylindrical vessels. One of the first methods employed was that of making a joint as

shown in Fig. 4. The welding was done from the outside and could be well finished. However, when the vessel was subjected to pressures from within, a combination of compressive and tensional stresses was produced at the weld, thus causing cracks. To overcome this difficulty, joints as indicated in Fig 5. were made. Where the metal is quite thin, sufficient contact of the surface can be secured by bending the metal outward to form a kind of a flange. By using more welding material than is necessary to produce a joint flush with the adjoining surfaces, a stronger weld can also be made.

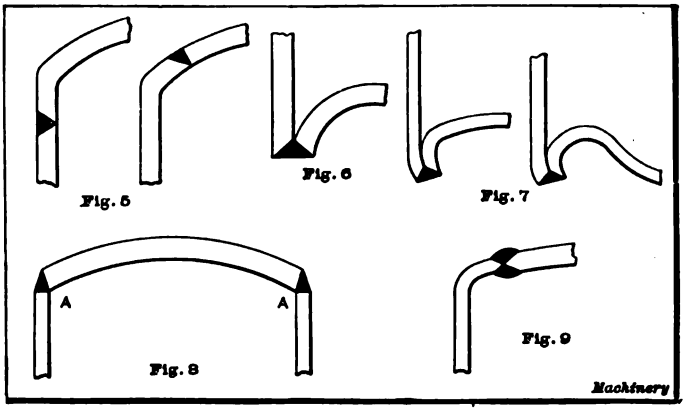



**Figs. 1 to 4. Illustrations showing Various Methods of Making Welded Joints**

In all these cases, the top or bottom is assumed to be convex on the exterior. Another method, shown in Fig. 6, is to make it concave on the outside. Such forms are especially suitable for bottoms. In Fig. 6, the rim of the bottom is bent and the edges of the bottom and of the cylinder are both beveled to provide a welding groove. Another method which does not necessarily include concaving is to bend up the rim of the bottom for a short distance, the dimensions of the piece being such that this rim snugly envelops the cylinder; the two may then be welded together.

The use of flat tops and bottoms should be avoided. The expansion and contraction of these during welding are different from those of the cylinder. The flat piece does not yield to the

cylinder, and, hence, the work is likely to be distorted. The convexing and concaving of the tops and bottoms provides a suitable margin for yield. Two forms of bottoms are shown in Fig. 7, in both of which elasticity in the diameter is provided for. The bending in of the edges enables the cylinder wall to support the bottom when the latter is under pressure from within. In some cases, it may be necessary to prevent diametral expansion of the cylinder when welding. A heavy removable band of metal in the form of a hoop may be used for this purpose. It is placed close up to the location of the seam. Most of the heat




**Figs. 5 to 9. Methods of Welding Tops and Bottoms to Cylindrical Shells**

from the cylinder will then be absorbed and dissipated by this hoop.

An interesting example of the application of the foregoing principles is afforded by a large containing vessel constructed by Munk & Schmitz, Cologne-Bayenthal, Germany. This vessel is a cylindrical shell, closed at the top and bottom, and is formed of sheets 0.40 inch thick in the cylindrical portion and 0.83 inch thick in the end portions. The vessel is 15 feet high and over 9 feet in diameter. All joints were made by the oxy-acetylene torch and the vessel successfully withstood, when tested, a pressure of 90 pounds per square inch.

**Welding Tops and Bottoms to Cylindrical Vessels.** — If the joining of the top to the cylindrical shell were made at the pre-

cise point where geometrically the side of the wall joins the top, as shown in Fig. 8, an outward pressure exerted from within and tending to produce a spherical shaped bottom would tend to make the angles at *A* more obtuse and would thus produce a tensional stress on the inner portion and a compressive stress on the outer portion of the weld. Hence, it should be carefully noted that this method of joining ends to cylindrical shells is objectionable, and that the methods shown in Fig. 5 should, in general, be adopted.

It is also very important in forming welds of the type described not to forget the effects of expansion and contraction. It is recommended that the weld be hammered during the cooling-off process. The hammering should be discontinued while the metal is still quite hot, and should not be continued below the point where a horseshoe magnet attracts the iron; in fact, at this point, one has perhaps gone a little too far. Subsequent to the cooling, the region that has been exposed to the high temperature should also be well annealed. This may be done by using two oil torches for gradual reheating, one from the inside and one from the outside. Incidentally it might be mentioned that in performing the welding operation it is also often advisable to use two welding torches, in which case a weld of the double-V character, as shown in Fig. 9, will be produced. The bottom of such a vessel should be so arranged that the weld is not located where the weight of the vessel itself comes upon it.

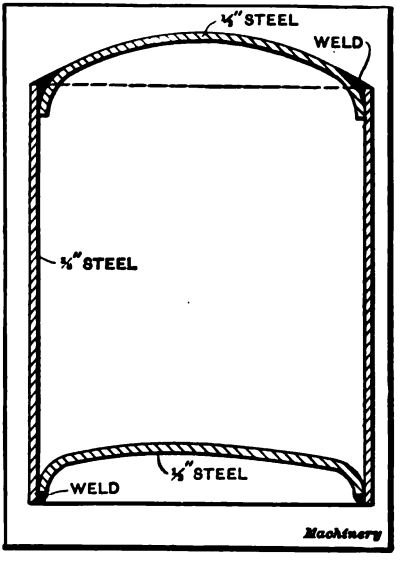
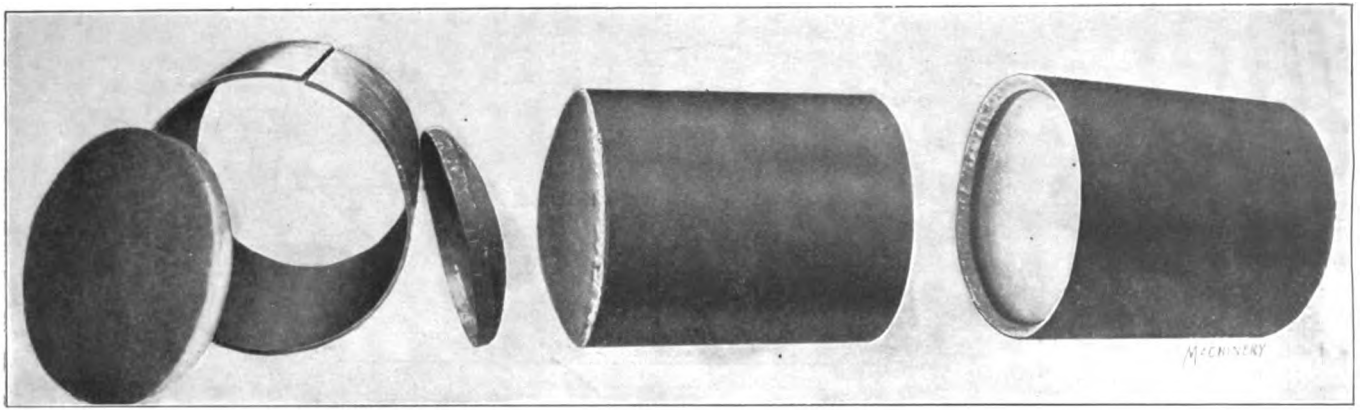



**Fig. 10. Example of Tank welded by the Oxy-acetylene Process**

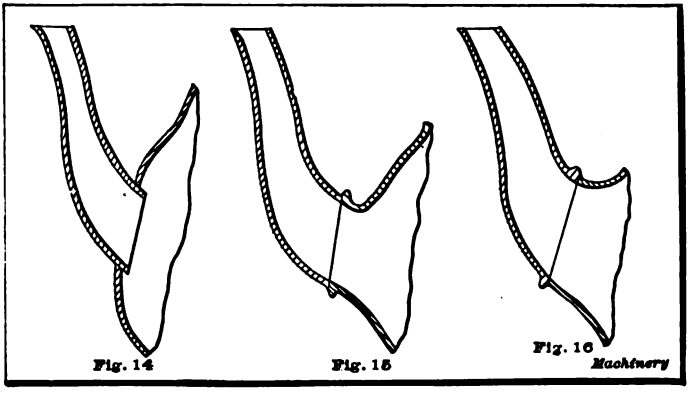
**Example of Welding.** — As a practical example, the illustrations, Figs. 11, 12, and 13, are shown, indicating the progres-



**Figs. 11, 12, and 13. Progressive Steps in Making the Tank shown in Fig. 10**

sive steps in welding a cylindrical shell, as well as the welding of a top and bottom to it. A diagrammatical view of a section of the welded container is shown in Fig. 10, the work being done by the Vilter Mfg. Co., Milwaukee, Wis. It will be seen that the top is convex and the bottom concave, as viewed from the outside. The shell is of $\frac{3}{8}$-inch boiler iron; the metal in the heads is $\frac{1}{2}$ inch thick. The tank is 20 inches in diameter and 24 inches long. Both heads fit the inside of the shell as indicated. After welding, this tank was tested at a pressure of 1200 pounds per square inch. For carrying out the test, a hole was drilled on one side of the shell and a nipple inserted after tapping. The tank was then connected with a hydraulic press pump. At 1100 pounds' pressure, the nipple started to leak, but there was no leak at the welded joints. A No. 7 Davis-

Bournonville tip was employed in making the straight weld in the shell, and a No. 8 tip was used for the ends. The straight weld was made in 45 minutes at a cost of $1.62 (exclusive of labor, but including depreciation); the circular weld at the convex end required 2.67 hours and cost $6.99; the circular weld at the concave end required two hours and cost $5.24. At thirty cents per hour, the labor cost would be about $1.63, making a total cost of $15.48. These tanks are used at a maximum working pressure of 300 pounds per square inch. A water-cooled torch was employed in part of this work.




**Figs. 14, 15, and 16. Methods of Welding Spouts to Household Utensils**

**Welding of Household Utensils.** — Some forms of household utensils, such as, for example, coffee and tea pots, cause considerable difficulties in their manufacture, particularly in connection with the attachment of the spout. Soldering has been used to a great extent in making these joints. However, the basic material of the solder is altogether different from the material united. The uses to which the vessels are put expose the joints to the action of acids, and galvanic currents are set up which injure the joint. Aluminum vessels are especially exposed to the action of these currents, because this metal is electropositive to nearly all of the common metals. One means to obviate the difficulty is to bend the metal of the main vessel or body inwards at the hole for the spout. The material of both the body and the spout is then bent into a fold on the interior, no soldering mate-

rial being used. The presence of this fold on the inside, however, is very objectionable. Even though it is closed when the vessel is new, the effect of repeated heatings is liable to open it, and the crevice becomes a trap for various small particles, which prevents effective cleaning. The oxy-acetylene welding presents the best solution of the foregoing difficulties.

**Joints for Household Utensils.** — When seeking to unite the spout and the body by the oxy-acetylene torch. the worker

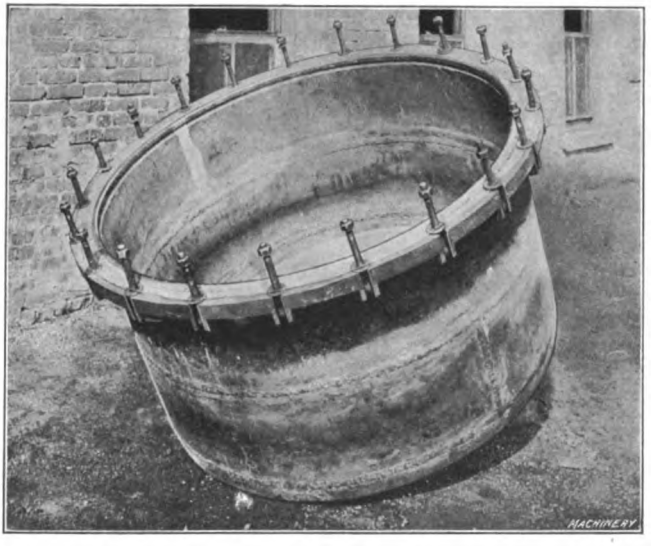



**Fig. 17. Example of Welding Copper. Kettle is 5 Feet 6 Inches in Diameter, 31 Inches Deep, and Used under Pressure. All Seams are Welded on Both Sides**

is, however, confronted with several difficulties, especially if the sheet metal is aluminum. The expansion and contraction of aluminum, due to temperature changes, as already mentioned, is very rapid, so that the operator must guard against distortions of the work. The melting point of the metal is low, so that holes are apt to be made in thin metal. Heated aluminum is very readily oxidized, with the result that a proper intermingling of the material is difficult. In view of these facts, it is recommended that the joint be placed away from the main body, that welding-wire be dispensed with, and that a suitable

flux be employed. In Fig. 14 is shown a joint which eliminates the necessity for the welding-wire; the spout fits closely into the hole and is introduced far enough to protrude about $\frac{1}{8}$ inch into the interior, the projection thus furnishing the welding material. There is considerable advantage, of course, in thus eliminating the handling of the wire as far as the worker is concerned, and another advantage is that the welding material is precisely the same as the material of the work. It is difficult, however, to operate on the interior, but this difficulty may be reduced

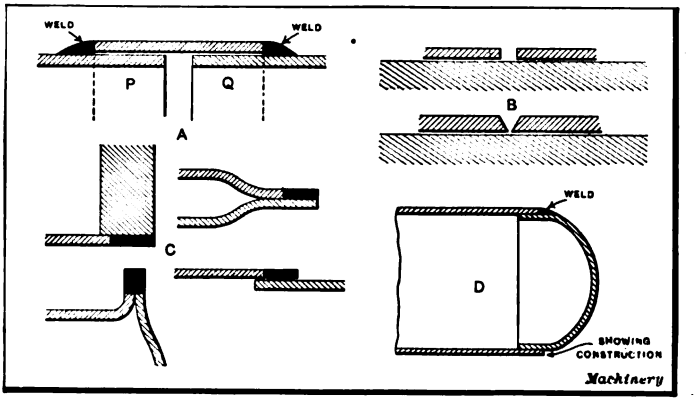



**Fig. 18. Recommended Forms of Joints**

by using a tip of special form. The appearance of the exterior, however, is good.

Another form of joint is shown in Fig. 15. Here the diameter of the hole is first made smaller than the interior diameter of the lower end of the spout. The material is then bent outwards to form a ridge of the same diameter as that of the spout end. The body and spout can then be butt-welded by using welding-wire. It is preferable, however, to bend the edge of the projection from the vessel outward, thus supplying the needed welding metal, or the auxiliary metal may be provided by bending the edge of the spout outwards, a joint of this kind being shown in Fig. 16. In either case, the ring of metal protruding at the joint will not be thicker than $\frac{1}{8}$ inch in a radial direction. In both cases, the interior is smooth.

**Design of Work for Welding.** — The design of work for welding is an important matter, and one which must receive careful attention in each individual case. The first point to be considered is that of the internal stresses set up by contraction in a welded piece as it cools. These stresses are inevitable, but may be greatly reduced by care in arranging the form and setting of the work. For instance, a boss or ferrule should not be welded onto a flat plate; the latter should be dished, and will then, if of good soft metal, adapt itself to the contraction stresses. In

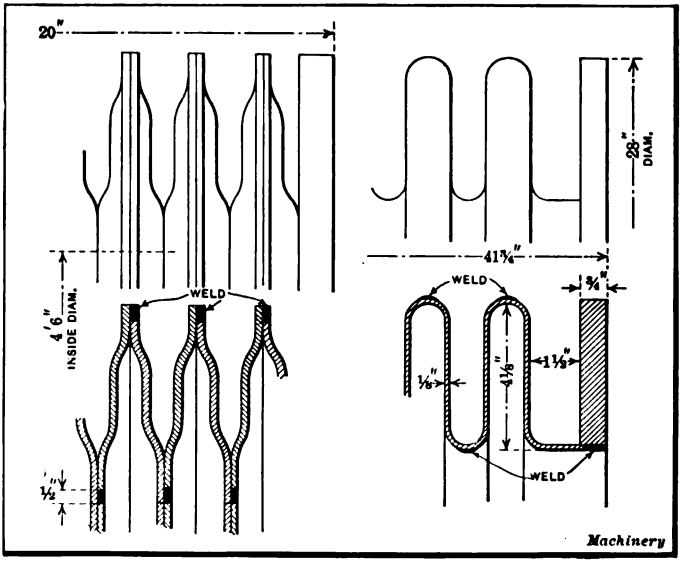


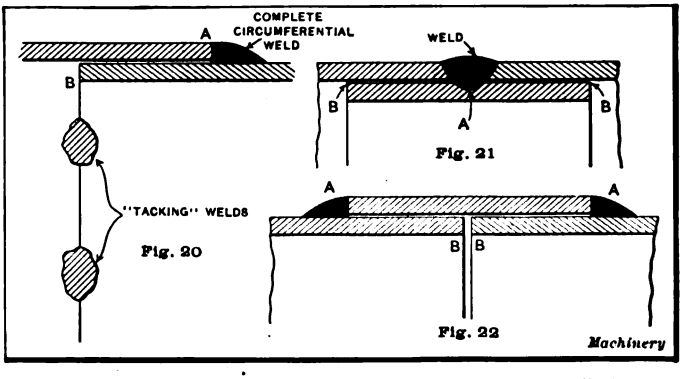

**Fig. 19. Welded Expansion Pipes**

building up tanks from flat sheets, it is impossible to avoid some buckling of the plates by thermal stresses, but the deformation can be kept to a minimum by a skillful operator.

In making a butt strap joint, as shown at *A* in Fig. 18, the butting plates should not be set in contact to begin with, otherwise contraction stresses will force them together and tend to shear the strap welds; there are no stresses of this nature if the plates *P* and *Q* are set slightly apart before welding on the strap. It is impossible to secure a weld of any considerable

depth between two flat surfaces in contact, and it is useless to adopt any design which depends upon this being done. Either the pieces must be set slightly apart or chamfered (or both), as shown at *B*, so that filling metal can be introduced and the weld built upwards from the bottom, or one piece must be shortened so that it makes quite a short flat contact with the second piece, metal being then built on to replace the missing part of the first piece and unite firmly with the second as it is worked into position (see black areas, at *C*).

The best design for welding an end into a cylindrical vessel to resist internal pressure is, as already mentioned, a matter of




**Figs. 20, 21, and 22. Circumferential Welds on Large Cylinders**

great importance; the Steel Barrel Co., Ltd., recommends the joint shown at *D*. The domed end is the form best resisting internal pressure, and, by fitting the flange of the end inside the cylinder, a good fit is easily obtained.

**Welded Expansion Pipe.** — Acetylene welded expansion pipes of the types shown in Fig. 19 have been built successfully in sizes up to 4 feet 6 inches internal diameter, to go between steam-turbines and their condensers or in the connection of gas-engine exhaust, steam separators, etc. About 1 in 10 or 15 lateral expansion or contraction is easily provided in an expansion pipe of this construction, 2 inches expansion, for instance, being taken up easily and safely by 20 inches or 30 inches of welded "concertina" pipe. The pipe shown to the left, in Fig. 19, is built

up from circular sections $\frac{1}{8}$ inch thick welded together along their inner and outer peripheries and welded onto a $\frac{1}{2}$-inch flange at each end, by building on metal as shown by the blackened areas. In the alternative construction to the right butt welds are made in the semicircular bends between sections. The butt welds can be made at the rate of 8 or 10 feet per hour, and the built-up welds at the rate of 5 or 6 feet per hour.

**Mixed Welding on Large Tank Construction.** — In boiler and still construction and in building up cylindrical tanks for oil storage or transport or for use as air receivers, etc. — where over-all dimensions are calculated by feet and plates $\frac{1}{4}$ inch or so in thickness are employed — it is usually convenient to make some joints by electric arc welding and others by the acetylene process. As regards the plate seams, the thickness of metal operated on is the same for both processes in any particular tank, but the longitudinal butt joints are most quickly and conveniently made by arc welding, while circumferential lap or strap joints, flange attachments, and end joints are best treated by acetylene welding. A longitudinal joint in a large cylindrical tank of $\frac{1}{4}$-inch plate can be made at about from 8 to 10 feet per hour by the electric arc process, while the main circumferential lap or strap joints can be made by the acetylene process at from 6 to 8 feet per hour.

In making a complete circumferential lap weld, it should be noted that the outside seam *A*, Fig. 20, should be welded all around the cylinder and the inside seam *B* simply tacked by short acetylene welds at intervals. These tacking welds hold the plate in position, but do not imprison air between the lapping plates; any attempt to make both welds *A* and *B* complete will cause trouble. For a similar reason, in the inside and outside butt strap joints shown, Figs. 21 and 22, complete circumferential welds must only be made at *A*, the seam *B* being left open or merely tacked down at intervals.

## CHAPTER X

### GENERAL CONSIDERATIONS IN OXY-ACETYLENE WELDING

It should be understood that what follows is written, not for the purpose of discouraging anyone who is considering the use of the oxy-acetylene apparatus, but in order to counteract the ideas which frequently exist, and which unfortunately are frequently cultivated by salesmen and advertising matter, that it is an exceedingly simple matter for anyone to learn to do good work by oxy-acetylene welding in a short time, and that, by following printed instructions, anyone can become expert. These fallacies are responsible for many disappointments, and the apparatus and method have been denounced many times, when the whole trouble lies in the lack of experience and knowledge, even where the apparatus is first-class and adapted to the purpose.

In his thirty years' experience with mechanical matters of many kinds, the author has not seen any process so apparently easy as the handling of any oxy-acetylene welding torch by an expert welder. He soon discovered, however, when he took a torch in his hand, that what appeared so easy was in reality a complicated matter, comprising, among other things, melting the metal, securing a good weld, adding metal and flux, keeping the melted metal from running away where it was not wanted, preventing hard spots, getting sufficient — but not too much — metal in the weld, avoiding pin holes and strains in the weld, keeping the parts in line, and handling the heated pieces. Besides all this, no two metals are amenable to the same treatment, and different pieces of the same metal often require vastly different methods to handle them successfully.

**Unusual Difficulties in Welding.** — Two examples may be mentioned to illustrate some of the difficulties met with in welding. The first is a three-throw crankshaft, with bearings about $3\frac{1}{2}$

inches in diameter which had the coupling flange, about 8 inches in diameter and $1\frac{1}{2}$ inch thick, broken off square at the end of the end bearing. The material was cast steel, and the shaft was very old, probably twenty-five years. The flange was bored out to within $\frac{1}{8}\frac{1}{2}$ inch of the size of the bearing, leaving just enough to set it by, some of the metal was melted down to tack it, and an attempt was made to proceed by using regular steel welding-wire, but this could not be done. Several different makes of cast steel were tried without success. It was finally necessary to melt down enough of the flange to extend entirely across the end of the bearing, about $\frac{5}{16}$ inch deep, and fill the rest with cast iron. There was no time to experiment, as an important ferry was tied up. At the time, some doubt was entertained as to the strength of the weld; but as it has lasted for three years, and as the break was probably caused by the timbers holding up the driving shaft (which was coupled to the crankshaft) giving way due to decay, there will probably be no more trouble.

The other case was a casting, apparently of brass, and weighing not more than three pounds. As is customary at the plant where the work was done, rolled Tobin bronze rods were used to weld it, but without success. It was found that the melting points of the casting and Tobin bronze were so different that a tip heavy enough to melt the casting would blow the Tobin bronze away before it could amalgamate with the casting. Fortunately, there were on hand some manganese-bronze sticks with a very high percentage of copper, which had been used experimentally, but were not suitable for ordinary work, and these proved satisfactory. Evidently the casting was a bronze with a high percentage of copper.

**Qualifications of a Welder.** — Some men become more proficient in the art in a shorter time than do others; but even with every facility at hand — the welding torch is not all that is needed — much experience is required to become an all-around welder. The average good machinist would require at least one year in a repair welding shop, before he would be competent to take care of all kinds of metal and the various jobs that come

in. One of the principal qualifications is ingenuity. The welder must never admit to himself the impossibility of any job. Whether it will pay to do it is another question, although it is frequently the determining one. A heavy weld in a cheap casting is possible but uneconomical, and it, therefore, should not be done unless loss of time in obtaining a new piece, or some other consideration, outweighs the purely financial one. Careful thought and planning may make a job financially possible, where the ordinary methods would result in the work not being done at all or being done at a loss. Ingenuity is required for such thinking and planning; and from it follow new methods, easier and cheaper, which result in an increase in knowledge and ability and in the advancement of the art.

**Trade Knowledge Required.** — It is not necessary for a man to follow any special trade in order to become a good welder; in fact, some knowledge of many trades is necessary, and the more known about them the better the welder is equipped. He should be somewhat of a machinist, blacksmith, boilermaker, patternmaker, molder, stationary engineer, electrician, and draftsman. He should have considerable knowledge of the construction and operation of automobiles, gas engines, and farm machinery. An acquaintance with contractors' machinery and methods of all kinds is valuable; and any mechanical experience that may have fallen to his lot is certain to be used sooner or later. A knowledge of the principles of the strength of materials is very useful in deciding how to reinforce a weak part in the best manner. For instance, it is common for a customer to request that his automobile frame be strengthened by welding a flat piece to the web of the channel inside, when equal strength with less weight and expense may be obtained by welding a piece to the inside or outside — preferably the latter — of the bottom flange, if that is where the tensile strain comes.

Experience proves that, in many cases, if a welded piece breaks, customers blame the welder, when full information shows that the fault is in incorrect construction or assembling. In many cases, it is probable that if the original stresses are put

on the parts repaired by welding, breakage will again occur and the work will be criticised adversely. One trouble that frequently arises, or rather a condition which causes trouble, is the inability or failure of the welder to discover the cause of breakage. At first sight, it would appear that this does not concern him, but when further consideration is given to the matter it will be seen that it is exceedingly important to know why a piece breaks. For example, the author frequently runs across cases where the piece is too light, and, if this is the cause, it is not fair to the customer to continue to weld the piece, unless he is made aware of the situation and advised that it will be cheaper and more satisfactory to have the piece made heavier, or made of steel instead of cast iron, for instance. Not only is it unfair to the customer to continue to weld a piece that is too light, but it tends to bring the process into disrepute, because the statement is sometimes made (although in the case of proper welding without any basis) that while the metal at the weld is strong enough, the original piece is damaged just outside of the weld. The reason for this kind of breakage is generally that the piece is too weak, although in the case of some metals, such as malleable iron, it is very easy to damage the metal outside the weld, as will be explained later. Aside from the above points, proper advice to a customer creates a feeling of friendship and good will that is an important business asset.

An experience bearing upon the application of welding, and incidentally illustrating the strength of welds, may be mentioned. A piece of cast iron had been welded several times, never breaking in the same place. When it was returned the next time, inquiry was made as to the advisability of rewelding it, and it was stated that the piece was so located in the machine to which it belonged as to be the weakest part, so that, if any excessive strains were to occur, this piece would break. The total number of welds eventually made in it was fourteen and the superintendent of the factory operating the machine later stated that the piece had been thrown away, as he was afraid that it was too strong to answer the purpose, inasmuch as there was very little left of it but welds.

**Training of Welders.** — One serious obstacle to the rapid development of oxy-acetylene welding in all branches is the difficulty of obtaining welders, and this is frequently and successfully urged against the purchase of apparatus. The Germans have overcome this difficulty by establishing welding schools, where not only workmen, but foremen, superintendents, and managers receive both theoretical and practical instruction. It is not believed that such work should be done by the government here, but the manufacturers of welding apparatus should, in their own interest, take such steps as would enable schools to be maintained. This is a subject which cannot be discussed here, except to say that Germany is far in advance of the United States in the development of oxy-acetylene welding, largely because of such instruction, and it is believed that a perfectly feasible plan can be readily developed to overcome the present deplorable lack of educational facilities here. Whatever system of education or training be adopted, it is essential that the welder be impressed with the importance and necessity of being absolutely honest, not only with his employer but with himself. There is no credit to anyone in having a piece returned with a defective weld, and a properly trained foreman can instantly determine if carelessness caused the defect. Two or three instances of such work should condemn a welder almost beyond redemption. Aside from this, it would be a serious matter to the average man to feel that any defective work he had knowingly done had resulted in injury to any of his fellowmen. Such accidents have occurred, and show clearly the need of proper education and the most rigid code of honor on the part of the welder.

**Welders on Repair Work.** — To obtain competent welders is not so difficult in a shop where the work is largely of one kind — thin sheet metal, for instance. In this case, the men become remarkably expert in a comparatively short time, and far more so than a good all-around man would be on their special work; but such a specialist is of practically no value in a repair shop, where he would have to handle not only all sizes of pieces, but all kinds of metals. The author has found that the only possible way is to employ a man who knows something about the prin-

ciples of the art, and to teach him, not so much how to weld but how to do the work so that as little machining or other finishing as possible has to be done after welding, and so that the piece can be used after being welded.

The average welder pays little attention to anything except welding, and if he secures a sound weld, he feels somewhat aggrieved if his attention is called to the fact that the part is out of line or full of hard spots, or has some other defect so that it is difficult if not impossible to use it. It is possible, however, to avoid machining in many cases by care on the part of the welder. For instance, a frequent accident to an automobile crankcase is a break through the side. No machining should be needed in such a case, and the faces and bearings should be just as true after the welding as before. It is admitted without argument that this is not commonly done, but it should be. Again, a stamping press frame, broken through one of the uprights, even if the section is as large as 4 by 16 inches, should never have the crankshaft bearings out of line with the platen more than 0.010 inch, and good welders repeatedly weld such pieces with less than half this error.

It is also strongly recommended that the superintendent, in a shop doing welding, himself learn to weld; not with the idea of doing the work, but so that he may be able to check the men as to the quality of their work and to decide how the work should best be done. It is easy to deceive a person who cannot weld, even when he is watching the work.

**Wages of Welders.** — A good welder is worth good wages. A proper consideration of the conditions will show that a careful man can save far more in the cost of gases than any wages which he is paid. Oxygen costs on the average, say, $2\frac{1}{2}$ cents per cubic foot, and a medium-size tip uses from 25 to 30 feet per hour, so that the oxygen expense runs from 60 to 75 cents per hour. The cost of acetylene will run, depending upon how it is made, from 20 to 50 cents per hour; the total is from $1 to possibly $1.25 per hour. It can be readily seen, therefore, that carelessness or slow speed on the part of the welder is very expensive, and that it is advisable to secure good men and pay them good wages.

In repair work, no consideration should be given to piece-work or bonus systems of paying the men. The author has had a great deal of experience with piece-work, and, under certain conditions, if properly handled, it is an admirable method of increasing earnings by stimulating men to eliminate lost time and useless work; but in repair work it is impossible to set any piece-work price that will be fair to both the workmen and the employer, and, for this reason, no attempt should be made to use it. A good welder of the proper temperament, who is paid good wages, will do good work, and this is the most important thing in welding, being far more essential than mere speed. Again, repair work is an art; and a self-respecting welder will not permit himself to be hurried beyond the rate which he considers essential to good work. At the same time, he will not permit himself to loaf; and a man who is so constituted that he will allow himself to do poor or slow work deliberately has no place in a repair shop.

**Rest Periods Required on Large Work.** — One of the objections raised by the workmen is the tremendous amount of heat given off by large pieces in a hot fire. A man cannot do good work unless properly protected, and, in some cases, it is impossible even with the best protection that can be afforded for a man to stand the heat for more than from 15 to 20 minutes. In such cases, enough extra welders should be provided so that a man will work one period and rest twice as long. This is particularly necessary on large welds that require from 8 to 10 hours to complete. A number of cases are on record where the actual welding extended over more than 24 hours. It has been found that 20 minutes of work and 40 minutes of rest for a man accustomed to such work is satisfactory; in one case, on account of the great heat, 15 minutes of work and 45 minutes of rest was found necessary. It is not advisable in moderately heavy welding to have a man stay at the work for more than 2 hours at a time.

**Cooling the Torch Tips.** — In heavy welding, the torch tips, if made of brass, are likely to become overheated, unless great care is taken, to such a point that the oxygen pressure will

blow off the end of the tip. This, as already mentioned, can be overcome largely by keeping a pail of water nearby, in which the end of the tip can be dipped when necessary. It is objectionable to dip the whole head of the torch, as this is likely to distort the end of the tip at the seat and cause a leak. The proper way is to dip the end of the tip into the water and cool it slowly. After the entire tip is cooled, the head may then be cooled, but not rapidly. This difficulty exists generally at the beginning of a deep weld where the whole head of the torch is surrounded by the hot metal. It has been found of great assistance to weld a piece of copper with the proper size hole in it onto the end of a brass tip, being certain that it is aligned carefully with the rest of the tip. This can be done by using a piece of the proper size drill rod. It will be found that this can be pulled out easily as soon as the weld is finished, if care is taken not to weld the drill rod to the tip.

**Care of Apparatus.** — The torches and apparatus should be taken good care of. If there are leaks in the connections, or other defects, they should be repaired at once. If the tips are defective and cannot be repaired, new tips should be provided. Good results cannot be obtained with defective apparatus. The quality of the apparatus purchased should be high. The market is flooded with cheap apparatus, such as torches, gages, etc. Imperfect apparatus will produce a welding flame, but will not give good results or be economical in the use of gases; also, they are frequently infringements of patents owned by manufacturers of the better apparatus, and, therefore, the user is liable for damages as well as the manufacturer. Only first-class apparatus manufactured by responsible firms should be used for welding.

**Overhead Cost.** — The average small shop of any kind is not usually run with the proper attention to the real cost of the work. This is particularly true in connection with welding, because it is not generally understood that there are other costs besides those of the gases and labor. Such expenses as interest, depreciation, insurance, repairs, taxes, advertising, soliciting, etc., have to be paid out of the earnings of the shop,

although they are generally not taken into account in the proper way. A large concern with competent accountants does take care of these things, and realizes that its customers have to pay for them in the price of the work. Many small welding shops have lost out by not paying attention to these matters. Again, the cost of gases is frequently taken at the invoice price without considering freight and cartage which have to be paid both ways.

There are a number of other items that must be taken into account in order that the proper cost of the work may be obtained. Assume that a plant cost $1000, and that the fixed charges will be as follows: Interest, 6 per cent; depreciation, 10 per cent; repairs, 5 per cent; insurance, 2 per cent; taxes, 1 per cent — a total of 24 per cent or $240 per year. The operating expenses might be about as follows: Rent, $35; heat, $5; light, $2; power, $5 — a total of $47 per month, or $564 per year. There will be miscellaneous charges, depending upon the work done, for welding-rods, hand tools, such as files, chisels, hack-saw blades, etc., charcoal, cartage, and some other things, which will run up to, say, $25 per month or $300 per year. If the welder is an all-around man, his labor will be worth at least 40 cents an hour. A competent solicitor will cost at least $75 per month or $900 per year. The total of these charges, exclusive of the welder's labor, amounts to $2000 per year. If oxygen is bought in 500-cubic-foot lots and costs two cents a cubic foot, the freight and cartage on it will probably cost $3 and $1, respectively, inbound. Outbound, the tanks weigh somewhat less, and it will be assumed that the freight and cartage amount to $3.50. This is a total of $17.50 or $3\frac{1}{2}$ cents per cubic foot. If two 300-foot tanks of acetylene are procured at once, costing two cents a foot, the freight and cartage will be about the same as in the case of oxygen, or a total of $19.50 or 3.25 cents per cubic foot. If the average size tip uses 25 feet of acetylene and 30 feet of oxygen per hour, the cost of operating the torch, aside from labor, will be $1.86 per hour.

To summarize: the cost per hour based on 3000 working hours per year will be as follows: Overhead, $0.666; labor, $0.40; gases,

$1.86; a total of $2.926. This would be true if the assumptions are correct and if the welding were going on ten hours a day. If a welder were only occupied in welding five hours per day, the cost of gases for the daily ten hours would be 93 cents per hour, making the total cost about $2 per hour. It is evident that care must be taken to insure proper charges being made for the work, although it is to be understood that the figures given are not actual, and that they will have to be modified to suit expenses which will vary with different locations. A common charge for machine shop work is from 60 to 75 cents per hour, and this is supposed to cover not only all expenses, but profit as well. The difference between these charges and those necessary to cover the cost and profit of oxy-acetylene welding are so startling that one is likely to feel that the process is very expensive. It should not be forgotten, however, that the cost per hour is not the correct basis on which to make the comparison. The results obtained should also be considered.

**Commercial Limitations of Welding Process.** — The above figures also indicate why in many cases it does not pay to weld inexpensive parts, and show the great necessity of employing competent welders, because it is evident that a small amount of time lost in doing a job may result in its costing more than can be charged for it; so that quick and accurate work must be done, and as little machining or finishing be required as possible, in the case of small or inexpensive pieces. There are many pieces that repair shops cannot weld profitably. For example, the sliding jaw of a vise frequently breaks off in front of the head, and while it is a perfectly possible job, and while the author knows of no case where one has broken after welding, it being possible to reinforce it considerably, the cost of welding compared with the cost of a new part is excessive. Again, if the vise is considerably worn, as is generally the case, it is a better investment to buy a new vise, as there is no lost motion, and the condition of the jaws is good. In such cases, experience and a thorough knowledge of the real cost of welding, including overhead expenses, is necessary in order to determine whether or not it is advisable to weld the broken part. In a number of such cases, policy may

require the work to be done, even at a loss, for the sake of securing larger work in the case of a good customer. Such questions have to be decided on their merits.

**Safety Precautions in the Oxy-acetylene Trade.** — The advantages of oxy-acetylene welding and cutting have led to its wide adoption in industrial plants. As a practically new trade, however, its hazards are not yet well appreciated. It is well, therefore, to call attention to certain precautions which should be observed in handling welding apparatus. If portability is desired, both the oxygen and the acetylene should be obtained from storage cylinders. A portable acetylene generator requires the removal of either the water or the carbide before the generator can be moved safely. Otherwise, if the generator tips over, the mixture of water and carbide will generate large quantities of gas, probably causing an explosion.

Accidents have occurred from using an open-flame light when cleaning out an acetylene generator. It is customary to wait until the pressure gage indicates no gas in the generator before beginning to clean it. Sometimes a small pocket of the gas remains, however, and burns the workman when ignition takes place from the open flame. Carbide will occasionally cake on the sides of the generator, and, unless the water is removed at once, the caked carbide will generate gas as it is knocked from the tank, and will ignite and burn the workman. A portable incandescent electric lamp should, therefore, be used, instead of an open flame.

The tubes or hose connecting the torch with the acetylene and oxygen supply are subjected to twists, turns, and abrasive action, causing minor leaks, and the fastenings may loosen and permit gas to escape. The torch itself or sparks from the welding will ignite the escaping gas. Occasionally, gas from loosened fastenings may gather about the clothing of the workman, become ignited, and severely burn the workman. The hose fastenings and the hose itself should, therefore, be frequently inspected for any leaks.

Little, if any, attention has been given to the effect of oxy-acetylene welding upon health. The heat from the flame is

sufficient to vaporize the metals, and, since the workman's head must be within a foot or two of the flame, he must breath the products of combustion unless protection is provided. A helmet, with a colored glass front, would afford this protection, as well as protection from the intense light.

Oxygen is usually sold in cylinders under pressures up to 1800 pounds per square inch. A defective cylinder may cause a destructive explosion. To guard against such accidents, the cylinders should never be stored in the working room, but in a special room with substantial walls. Full tanks should not be left in places where the direct rays of the sun may strike them, or close to heating apparatus or other sources of heat which would cause dangerous expansion.

**Strength of Welded Forgings.** — Sometimes trouble occurs, particularly in the case of forged steel parts, from not realizing that an oxy-acetylene weld is really only a casting, and that even with the best possible work the weld will not be as strong as the original piece. If a forged steel piece is broken by carelessness or accident, it may be possible to weld it so that it will be strong enough, particularly if there is space enough to reinforce the weld sufficiently. On the other hand, if it has to be machined to the original size, and if the fracture is caused by the part being originally too light, the chances are that unsatisfactory results will be obtained in service. It is doubtful if any attempt should be made to weld many kinds of steel forgings. This is particularly true in the case of alloy steels, such as vanadium steel, chrome-nickel steel, etc. These materials occur usually in automobile parts, their use not being frequent in ordinary machinery. It appears useless to weld such pieces, as they cannot be made anywhere nearly as strong as they were in the first place. Particularly objectionable is the welding of certain parts of an automobile, such as a steering knuckle, where the spindle has broken off. Many such parts have been welded and held satisfactorily, but it is not recommended and should not be done until after the customer's attention is called to the danger, and he has agreed to accept the responsibility for any damage. Even then it is advisable not to run the risk. If it is

remembered that cast steel is never as strong as rolled or forged steel, it is hardly possible to use wrong judgment as to the advisability of welding. It is better to err on the side of safety than to take chances.

A further reason for being careful in welding steel is on account of the peculiar property of this metal, which requires that, under alternating strains, a certain proportion of the elastic limit must not be exceeded, otherwise a fracture will occur in the course of time. Now the elastic limit of cast steel, no matter how good, is far below the elastic limit of forged and heat-treated steel, particularly alloy steel. Therefore, a fracture will occur much sooner in the case of a weld than in the case of the original piece, even if the weld is sound. Much could be done in the way of strengthening the weld, if it were possible to heat-treat it properly, but this branch has not, so far, been developed in connection with welded parts.

**Tests on Strength of Welds.** — With regard to the strength of welds, the author knows of no comprehensive tests that have been published, and does not believe that any investigations that have been made are complete enough to warrant accurate conclusions, particularly when modern welding practice is considered.

*Cast Iron.* — In the case of cast iron, it is well known that the weld is stronger and less brittle than the original material; that is, as far as any ordinary cast iron is concerned. An explanation of this is to be found in what may be called the "anatomy" of the weld. It is finer grained, and, inasmuch as the welding-rods have to be made of good material, it is generally of a better quality than the original casting. It is, therefore, hardly necessary to discuss in detail the strength of cast-iron welds.

*Steel.* — With regard to steel, the situation is very complicated. There are so many different kinds of steel, and they are used for so many different purposes, and are subjected to so many different kinds of strains, that it is impossible to lay down any general rule as to the strength of welds in this material. It has been claimed that oxy-acetylene welds are brittle and hard

although they may have greater tensile strength than that of the original material. It is true that in the early days of oxy-acetylene welding, when torches did not give as nearly a neutral flame as they do at the present time, many welds were burnt, and were, therefore, brittle and hard. At the present time, however, any weld of this character shows that the welder either used a poor torch or did not know how to handle it. Hardness and ductility are relative terms, and a weld in a very soft, ductile, low-carbon steel may be harder than the original material, while a weld made with the same welding-wire in a much harder steel of higher carbon may be softer than the original weld. In the former case, the original material may be more ductile than the weld, while the opposite may be true in the case of a harder original material. Again, the effect of the heat on the added material will be approximately the same in both cases. It is not true, however, that the effect of the heat will be the same on the original material in both cases. In the case of the soft ductile steel, the tensile strength of the weld will undoubtedly be higher than that of the original material, while, in the other case, the tensile strength will be less, and it may even happen, in the second instance, that the material just next to the weld will be so badly damaged by the heat that the test-piece will break there, and neither in the weld nor some distance away from it. In the case of the higher carbon steels, there is a still different action in that the material next to the weld and in other places, where the heat is high enough, is decarburized. The extent of this decarburization varies with the intensity of the heat and the time to which the piece is subjected to it. A higher temperature and longer continued heating remove more carbon. This action is not due to anything except the heat and the presence of the oxygen in the air, and would occur with any method of heating. Another thing that occurs with very high carbon steel, such as tool steel, is the burning of the original metal in the vicinity of the weld. This applies particularly to tool steel, and an examination of many specimens microscopically indicates that it is not possible to weld high-carbon steel without burning it. Of course, it is possible that the union may

be strong enough for certain purposes, but the material next to the weld is not sound, and no method of annealing or heat-treatment will cure steel that is really burnt.

**Ductility of Steel Welds.** — With regard to the ductility of steel welds, Figs. 1 and 2 show some test-pieces nearly full size, before and after bending, the weld being made in the center of the test-piece. It cannot be claimed that such welds are brittle or lack ductility. Fig. 3 shows, full size, a similar weld made in the same material and flattened cold. This also shows that a properly made weld is ductile. In the particular cases shown,

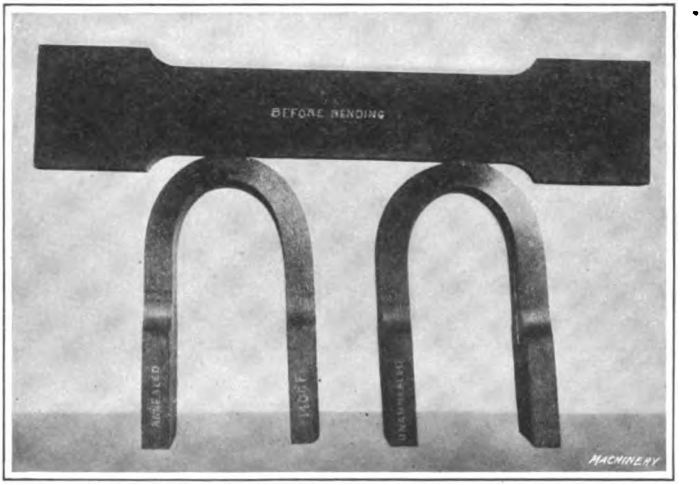



**Fig. 1. Test Specimens showing Ductility of Welded Joint**

the test-pieces broke about $2\frac{1}{2}$ inches from the weld, but the material from which they were made was a very low carbon steel of 47,500 pounds' tensile strength; hence, it would be naturally expected that such material would not break in the weld. With steel of about 55,000 pounds' tensile strength, a welded test-piece will usually break in the weld, giving a tensile strength of about 52,000 pounds. The elongation in such cases may run as high as 20 per cent, that of the original material being in the neighborhood of 32 per cent. The elastic limit will be about 33,000 pounds, against 35,000 pounds in the original.

So much depends upon the material with which the weld is made, on the method of making it, and on the heat-treatment after it is made, that it is impossible to give any specific results. All of the published tests that the author has seen are, in his opinion, deficient in essential information. For example, in one report of some tests made about two years ago, calling the average of the original pieces 100 both for tensile strength and elongation, the average for the welds untreated in any way was only 85 for tensile strength and 22 for elongation. The author's belief is that these welds were in some way improperly made, as he has never obtained such low figures as these. The lowest results given are for tensile strength, about 80 per cent of the original, and for elongation, 9.3 per cent of the original.

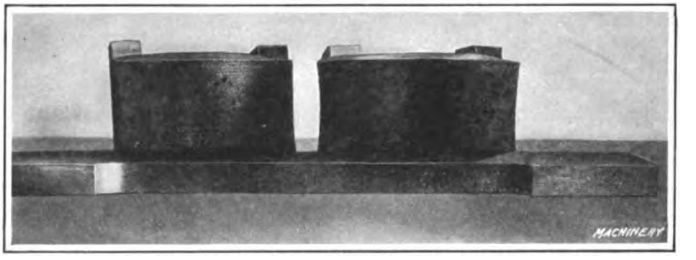



**Fig. 2. View from above of Test Specimens shown in Fig. 1**

This latter very low result indicates clearly that there was a wide variation in the actual condition of the different welds, which should not exist. It is admitted that there will be some variation, but the author has repeatedly obtained results with a maximum variation of 10 per cent in the elongation, 6 per cent in the elastic limit, and 5 per cent in the tensile strength. As has been stated before, it cannot be claimed that any weld is as good as the original material; and particularly in the case of steel, which is generally used in places where great strength and high physical qualities are required, great care should be taken and good judgment used in selecting the method of joining. There is one thing that should be carefully considered, and that is, whether a welded piece is to be subjected to alternating stresses or shock. This is the worst condition to which a weld

can be subjected, and it is well known that a piece of over-annealed steel will not stand these stresses nearly as well as a piece that has been properly refined by correct heat-treatment.

**Strength of Welds in Non-ferrous Metals.** — With regard to the strength of welds in other metals, the author is not acquainted with any conclusive published tests, and is unable to give any results. However, in a general way, if the welds are made carefully with a good torch and the proper materials, the results will usually be satisfactory, as, in most cases, such metals as brass, bronze, aluminum, and copper are not subjected to any great stress, although, of course, there are exceptions to this; so that a weld in these materials will usually be amply strong, even if not equal to the strength of the original material. One point,

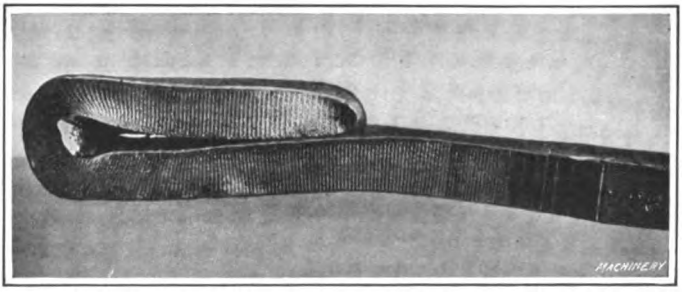


Fig. 3. Test Specimen bent Cold, showing Ductility of Weld

however, should be noted, which is that, in the case of brass and bronze castings subjected to pressure, it is good practice, if not absolutely necessary, that the whole piece be annealed at the proper temperature in order to relieve cooling strains caused by the welding. What this annealing is depends upon the alloy, and no definite instructions can be given. The time and temperature of annealing, and the rate of cooling all have their effect, and have to be determined in each case of importance.

**Miscellaneous Applications of the Oxy-acetylene Flame.** — The oxy-acetylene flame is used not only for welding and cutting purposes, but also for the rapid heating of machine parts for various purposes. One of the applications is for heating steel for case- and surface-hardening. It is especially useful for so-

called "local hardening," because the oxy-acetylene flame furnishes a highly concentrated and very intense source of heat, which permits of local heating with excellent results. For local hardening, for example, it is possible to heat only that part which is to be hardened to the required hardening temperature, quenching it in water as usual. The other parts of the object which have not been heated to the hardening heat will remain soft as before. The same results as obtained by casehardening can also be obtained by the use of the oxy-acetylene torch. By using a well-regulated flame to heat the steel, and afterwards permitting a slight excess of acetylene to impinge upon the piece to be case- or surface-hardened, it is possible to obtain quickly a carburized surface on the metal being treated, the carbon in the acetylene gas furnishing the required carbon for casehardening. It is important, however, that the inside tip of the flame be kept at a distance of at least 1 inch from the surface being treated. If the flame is regulated in this manner, the free carbon liberated by the excess of acetylene is absorbed by the metal while it is kept at the carburizing temperature by the flame. It has been ascertained by experiments that, if the inside tip of the flame is too close to the surface to be treated, it will be transformed into a white cast iron, whereas, if the tip of the flame is kept at a distance of from 1 to $1\frac{1}{4}$ inches from the surface, it will be evenly carburized and will assume on the surface the properties of tool steel.

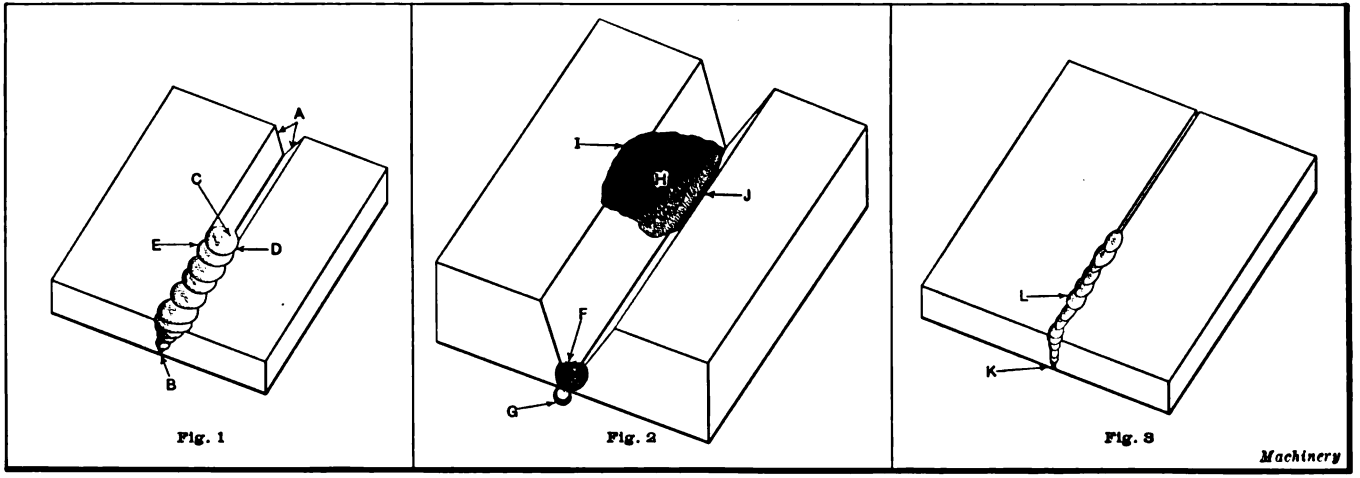
The use of the oxy-acetylene torch for casehardening mild steel should not be confused with its use for local hardening of high-carbon tool steel. In the former case, the flame is used for carburizing as well as for heating, while, in the latter case, it is used for obtaining the hardening temperature only. In this case, the part of the object that is not to be hardened may be kept cool by immersing it in water, while only that part which is to obtain a hardening heat is beyond the surface of the water and acted upon by the oxy-acetylene flame. When the required temperature has been reached, this portion also is immersed in the water, a local hardening effect on the heated portion thereby being secured.

# CHAPTER XI

## LEAD BURNING

LEAD burning may be defined as a form of autogenous welding, whereby the parts to be united are joined by melting metal between them. This molten metal is obtained by heating the end of a strip of lead of the same composition as that of the lead plates to be united. The addition of metal at the joint is not actually necessary, but it serves to replace the material that was cut away before welding, and the cutting away of metal at the point of fracture is a desirable practice, as it enables the welder to work more rapidly and do better work. The term "lead burning" is really a misnomer and should never have come into use, because the lead is not burned so long as the welder does his work properly. It would be just as proper to call the welding of iron or steel with the oxy-acetylene flame "iron burning" or "steel burning," as to call the process of welding lead by the oxy-hydrogen flame "lead burning." The operation is essentially one of welding the lead with heat furnished by the combustion of hydrogen, and the technique of the operation is almost exactly the same as that of ordinary oxy-acetylene welding. Lead burning may be effectively performed with an oxy-acetylene welding torch, and a skillful welder will soon learn the art of lead burning, using the same torch with which he welds iron or steel; but great care must be taken, because the temperature of the oxy-acetylene flame is really too high for working on lead.

**General Practice of Lead Burning.** — This chapter is concerned with the usual method of lead burning, and, for this purpose, the gases used in the torch consist of hydrogen under a pressure of from one to two pounds per square inch and air under about the same pressure. The torch in which the hydrogen is burned is designed to mix the hydrogen and air in the correct proportion, and a jet tube in the burner directs the flame against the




**Figs. 1, 2, and 3. "Burning" a Joint, starting a "Burn," and Joint "burned" without beveling Plates**

work at the desired point. To obtain satisfactory results, the flame must have a very fine point. Fig. 1 shows the method usually employed in joining two sheets of lead, the procedure being as follows: The edges of the sheets are first beveled at *A* so that a small trough is formed with an included angle of from 24 to 30 degrees. The welder then starts at one end of this trough *B*, and the oxy-hydrogen flame is allowed to play against the edges of the work until the surfaces of the lead are softened almost to the running point.

Considerable judgment is required to determine the exact instant at which the lead is on the point of melt-

ing, and the ability to do this, hour after hour throughout the working day, can only be acquired as the result of wide experience. Just before the lead comes to the melting point, the welder brings his strip of lead or so-called "solder stick" into the flame and heats a small portion of it so that a drop of molten lead will fall into the joint at *B*, at the instant that the temperature of the lead at each side of the groove has been raised to the melting point and is about to be changed to the molten condition. At the instant that the drop of lead falls into the groove, the flame is whisked to one side and the drop of molten metal breaks through the heated surface at each side of the groove, uniting with the metal in the plates. The welder carefully observes the falling of the drop of lead and its union with the metal in the plates, and if there is the least indication that all the metal has not united properly, he applies the flame at that point for a sufficient length of time to remelt the metal and allow it to flow together.

An attempt has been made at *C* to show the perfect union of a drop of lead with the metal in the plates. It will be seen that this is quite different from the well-defined line between the drop of metal and plates as shown at *D* and *E*. The latter condition results when the temperatures of the drop of metal and the metal in the plates are not the same or where the temperature has not been raised sufficiently; but at *C* the temperatures were correct, with the result that the lead in the drop united with the lead in the plates in such a way that no junction line can be seen. In fact, there is no line of connection or anything that can properly be called a point, as the metal has united to form a homogeneous body. This is the condition which will be produced by a skillful lead burner. From *B* to *C* are shown several small globules of lead that have been melted into the joint and allowed to unite with the lead plates. It will be noted that these completely fill the groove. If all of the drops are of the same size, and are deposited in a straight line, it indicates that the work was done by a skillful lead burner; and although the beginner may secure a strong and perfect joint between the plates, it is probable that the drops of lead that he deposits in the joint will be of irregular shape and size, and will not be in a straight line.

**Starting the Lead Weld.** — Fig. 2 shows how a joint may be started, and also illustrates some troubles which may be experienced by a lead burner. At *F* the flame was applied to the work for too long a time, with the result that some of the lead *G* has melted and run out of the joint. This must be replaced from the "solder stick" and causes a loss of both time and material. The hole shown at *H* was caused by holding the flame on one side of the joint too long, with the result that the metal melted and flowed away at the point *I*. This condition will cause irregularity in the finished seam and remain as a permanent indication that the work was done by a careless or inexperienced operator.

It will be noticed that at *J* the edge of the sheet has not been melted back; it is still in line with the unwelded part of the plate and there is a probability that a leak may be found at this point when the completed joint is tested. The most skillful welders melt the edges of the plates back far enough to be sure that all the beveled edges of the metal have been heated to the melting point. It is possible to heat the edges of the plates so accurately that the metal will unite with the drops of lead without actually melting back the beveled edges; but the safer plan is to melt the lead back at each side of the joint for at least $\frac{1}{32}$ inch, in order to be sure that a perfect union has been obtained.

**Lead Burning without Beveling.** — Fig. 3 shows the result of attempting to burn a joint with square-edged plates. This method may be employed on very thin plates, but it is doubtful whether or not a perfect joint will be secured. In attempting to weld two square-edged plates, the lead burner starts at end *K* and must melt the top edge of the plate before the lower edge can be heated. By the time that some point *L* is reached, other difficulties will be encountered. One difficulty is in having to drive the heat down through a layer of molten metal, in order to heat the plates to their lower edges, with the result that there is likely to be a large part of the lower edges of the plates which has not been properly joined, but where the plates have been beveled at the edges, as previously described, the welding is done at the lower edges first, and a strong and uniform joint is secured.

**Apparatus Used for Lead Burning.** — The apparatus used for lead burning consists of a burner provided with two lines of rubber tubing about $\frac{1}{4}$ inch in diameter, which connect the burner with suitable sources of air and hydrogen. Rubber tubes from 50 to 75 feet long are sometimes used in order to give the welder sufficient latitude to work inside of large tanks. Metal pipes

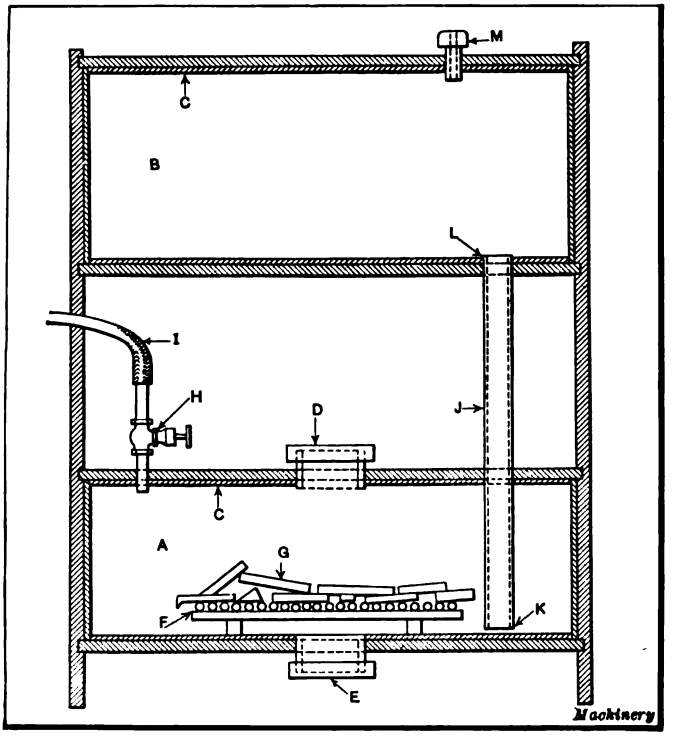



**Fig. 4. Cross-sectional View of Hydrogen Generator**

may be used for part of the distance, but it will usually be found more satisfactory to provide a sufficient length of rubber tubing to reach from the source of oxygen and hydrogen to the most remote point at which welding is to be done. The hydrogen generator should be located out of doors, because it gives off noxious gases while in operation. The hydrogen may be stored in pressure tubes and delivered through a reducing valve which

will maintain the pressure between one and two pounds per square inch. The air supply may be obtained by any convenient method. A hand pump can be used where power is not available, but, in most cases, a small motor pump will give satisfactory results. A small gasoline engine will be found satisfactory for driving the air pump, if no other source of power is available.

**Hydrogen Generator.** — Fig. 4 shows the arrangement of a hydrogen generator of the type used for lead burning. This is usually constructed of 1-inch boards screwed together with brass screws, as iron is quickly corroded by the acid fumes. The inside of the generator is covered with lead, and the seams between adjacent lead plates should be burned together, as the tin contained in solder would be quickly attacked by the sulphuric acid used in producing the hydrogen. The generating apparatus consists of two tanks located one above the other; and the vertical distance between these tanks regulates the amount of pressure on the hydrogen. The two tanks *A* and *B* are made in sizes about 8 by 8 by 24 inches, and are furnished with a lead lining *C*. The lower tank has an inlet *D* fitted with a screw cap which may be removed for charging the tank with dilute sulphuric acid. A similar opening is provided at *E* for cleaning out the tank and removing the residual sludge which remains from the spent chemicals. The grating *F* is made of wood or metal bars covered with lead, and this grating supports the iron or zinc *G*, which reacts with the sulphuric acid to generate hydrogen. Valve *H* provides for shutting off the flow of hydrogen when the apparatus is not in use, and there is a second valve at the burner that is used for the same purpose; but valve *H* should always be closed when it is required to shut the gas off for a considerable period of time, in order to relieve the rubber tubing from strain. The arrangement of the rubber tubing and the method of connection are shown at *I*. A pipe *J* connects the upper and lower compartments of the generator, the entrance of pipe *J* into the upper compartment being just flush with the lead lining at *L*, to which it is joined by burning. It will be obvious that pipe *J* must be made of lead and that it must also be tightly joined to the lining of the lower compart-

ment into which the pipe projects almost to the bottom, as shown at *K*.

**Operation of Generator.** — The method of operating the generator may be briefly described as follows: The iron or zinc *G* is placed in position on the grating *F*, and clean-out pipe *E* and valve *H* are tightly closed. Sulphuric acid diluted with water is next poured into the generator through opening *D* until tank *A* has been filled within about 2 inches of the top. The introduction of the acid should be done as rapidly as possible, after which opening *D* is closed immediately, as hydrogen is liberated the instant the acid comes into contact with the metal at *G*. As the gas is generated, it rises through the liquid and soon fills the space at the top of tank *A*. Continued liberation of

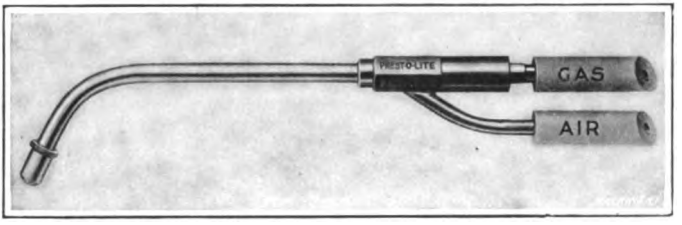



**Fig. 5. Modern Lead-burning Torch which uses Acetylene and Air**

gas causes pressure to be set up in tank *A*, which results in forcing a portion of the liquid up through pipe *J* into upper compartment *B* of the generator. In case none of the gas is drawn off through valve *H*, more and more of the liquid will be driven up into tank *B* until the level of the liquid in tank *A* has fallen below the level of grating *F*, with the result that metal *G* is removed from contact with the acid, which causes the generation of hydrogen to be automatically stopped.

If, however, any of the metal *G* falls through the grating into the bottom of tank *A*, generation of hydrogen will continue until the piece of metal is entirely oxidized. This continued generation of hydrogen will result in driving the liquid up through pipe *J* into upper compartment *B* until the lower end of pipe *J* is uncovered. This will allow hydrogen to escape through pipe *J* into the upper compartment of the generator, from which

it escapes through vent *M* provided for that purpose. Vent *M* also provides for the escape or entrance of air as the liquid enters or leaves compartment *B*. In this way, pressure is maintained upon the hydrogen, the amount of pressure being determined by the difference of level of the liquid in compartments *A* and *B* of the generator. The arrangement is such that the pressure

**Fig. 6. Complete Lead-burning Outfit in which Air and Acetylene are used**

is usually slightly over one pound per square inch. When all of the liquid is forced up into compartment *B*, the pressure will naturally be somewhat higher than it is when most of the liquid is in compartment *A*, but the maximum variation is not more than 8 or 9 ounces, and exerts little effect upon the action of the flame at the welding point. When hydrogen is drawn off from tank *A*, especially if it is drawn off faster than the gas is

being generated, liquid flows down through pipe *J* into the lower compartment, *A*, so that the action of the generator is entirely automatic as long as the supply of metal *G* and dilute sulphuric acid lasts. Vent tube *M* may be closed with a pipe cap through which several small holes have been drilled, to prevent large pieces of dirt and insects from finding their way into the tanks.

**Modern Lead-burning Outfits.** — Since the development of the method of generating acetylene by the chemical reaction of calcium carbide and water, the apparatus used for lead burning has been materially simplified by the substitution of acetylene gas for hydrogen. In most modern lead-burning outfits, the blower or pump for supplying the necessary amount of air has also been dispensed with and a tank of compressed air is substituted, which has a suitable reducing valve to regulate the pressure. Figs. 5 and 6 illustrate a modern lead-burning torch and a complete lead-burning outfit, respectively, these equipments being of the type manufactured by the Prest-O-Lite Co. Fig. 6 shows a regular oxy-acetylene welding outfit provided with a bench regulating block, acetylene and oxygen tanks, and suitable reducing valves. To change this outfit for use in lead burning, the oxygen cylinder is replaced by a tube of compressed air, or the torch may be supplied with air by any convenient method. The ordinary welding torch may be used, or a more simple torch may be employed. Fig. 5 shows a torch of simple design, especially intended for use in lead-burning operations; it is not provided with the adjusting valve required on the oxy-acetylene torch, and the combustion of acetylene is effected by supplying air to the torch in place of pure oxygen. This reduces the intensity of the temperature of the flame to such a degree that it is suitable for melting lead without causing excessive oxidation or danger of melting the metal too rapidly.

# CHAPTER XII

## CUTTING METALS WITH THE OXIDIZING FLAME

To the general public, the method of cutting steel by the use of the oxy-acetylene or the oxy-hydrogen torch is probably better known than the operation of welding. It certainly is more spectacular, on account of its application to the wrecking of burned steel frame buildings, obsolete bridges, etc., which is work that is generally done in view of a large number of people. As a general rule, the cost of cutting metal by this process is less than by any other means, and, in some cases, the saving effected is very great. For instance, in armor-plate plants, it is common practice to cut 16-inch armor plate at the rate of nineteen feet per hour, a speed which cannot be attained by any other process. This is done at an expense so low that it is not comparable with the cost when done by ordinary machines. The time element enters largely into such cases, as well as the fact that irregular shapes can be produced as readily as straight lines.

**Principle of Method.** — The principle of oxy-acetylene or oxy-hydrogen metal cutting is based on the fact that, if a piece of steel or iron is brought to a red heat and a jet of pure oxygen is turned against it, the metal will be oxidized or will burn. It is frequently thought that the process is one of melting the metal. This is not correct, as the metal is simply burned away where the jet of pure oxygen comes in contact with it. In other words, it is simply an intensified form of oxidation or rusting.

**The Cutting Torch.** — The ordinary cutting torch consists of a heating jet using oxygen and acetylene, oxygen and hydrogen, oxygen and coal gas, or, in fact, any other gas which, when combined with oxygen, will produce heat. By the use of this heating jet, the metal is first brought to a sufficiently high temperature, and an auxiliary jet of pure oxygen is then turned onto the red-hot metal, when the action just referred to takes place.

The early form of torch for cutting was generally an ordinary welding torch with an extra tube carrying the auxiliary oxygen at the necessary pressure, which was clamped to the welding torch when it was desired to cut. Of course, the cutting jet has to follow the welding jet, and, hence, such torches were unsatisfactory, because it was necessary to turn them around when the direction of cutting was changed. It was also difficult to bring the cutting jet as close to the welding jet as desirable. Later the auxiliary jet of oxygen was placed between two or more welding jets in one tip, so that no matter what the direction of the cut, the torch could be held in the same position, making it more convenient for the operator and consuming much less time.

**Hand and Machine Cutting.** — The operation of cutting is one that is very readily learned. The difficulty increases considerably with the thickness of the metal, but, for all ordinary thicknesses, a few hours' instruction will enable good and economical work to be done. It is impossible, however, to cut very smoothly by hand, as the torch cannot be held sufficiently steady to do work which requires great accuracy. Cutting machines have, therefore, been produced which not only cut straight and clean, but also make a very narrow kerf, which implies a considerable reduction of the oxygen used, as compared with that consumed in hand cutting.

**Cleaning Work to be Cut.** — The principal difficulty encountered in cutting is the presence of scale, rust, paint, or other foreign matter, which will not burn, or which interferes with the passing away of the slag or oxide formed during the process. It is, therefore, advisable, and in many cases absolutely necessary, to remove these substances before doing the work. For example, in cutting up old boilers in a district in which the water contains lime or other impurities, it is almost certain that the inside of the boiler sheets will be coated with scale. This scale must either be removed by pounding the outside of the boiler with a sledge at the points where the cuts are to be made, or it must be chipped off from the inside. In the case of bridges with several heavy coats of paint, it is sometimes necessary to remove part of it by burning off with an ordinary gasoline torch, or by some

other method. Not only is time saved by doing this, but the consumption of oxygen, which is very much greater in cutting than in welding, is greatly reduced. Without exception, it pays to take the precaution of removing such foreign matter.

**Procedure in Cutting.** — In cutting a comparatively thin piece, say, $\frac{1}{2}$ inch thick, a beginning can be made at the top and edge of the piece by holding the heating flame at that point, and, as soon as the metal becomes red-hot, turning on the auxiliary jet of oxygen. The thickness is not sufficient to prevent the slag from being blown out through the bottom of the cut, which is necessary in all cases. It is evident, however, that, in the case of a somewhat thicker piece, it would be advisable to begin at the bottom of the edge instead of at the top, so that the slag would be sure to be blown out and fall through easily. It is apparent that the thicker the piece, the higher must be the pressure of the auxiliary jet of oxygen to force out the slag. It will also be clear that unless the slag is kept in a melted condition, it will clog the bottom of the slot and stop the proper action of the torch.

Any lack of continuity in the piece being cut, such as a blow-hole in a steel casting, will make it impossible to cut through the piece. This is the reason why it is more difficult to cut through two or more pieces of sheet steel riveted together than through a single piece of the same thickness. The mill scale on steel sheets is not generally removed when they are riveted together and this breaks the continuity of the metal in the joint. It has been found possible, however, to cut as many as twelve or fourteen pieces of material, $\frac{1}{4}$ inch thick, if the scale is cleaned off and the pieces clamped together tightly. This can be done by hand only with difficulty, although it is readily done, and a smooth, clean, and uniform cut obtained, when the work is done on the "oxygraph" or a similar power-driven machine. The possibility of cutting a number of pieces at the same time reduces the expense of such work materially, and makes profitable some operations which, if they had to be performed on single sheets, could not be done economically on account of the high cost of labor and gases.

**Rules for the Operation of Cutting Torch.** — When starting a cut, the steel is first heated by the welding flame; then the jet of pure oxygen is turned on. The flame should be directed a little inward, so that the under part of the cut is somewhat in advance of the upper surface of the metal. This permits the oxide of iron produced by the jet to readily fall out of the way. If the flame were inclined in the opposite direction or in such a way that the cut at the top were in advance, the oxide of iron would accumulate in the lower part of the kerf and prevent the oxygen from attacking the metal. The torch should be held steadily and with the cone of the heating flame just touching the metal. When accurate cutting is necessary, some method of mechanically guiding the torch should be employed.

**Thickness of Metal that can be Cut.** — The maximum thickness of metal that can be cut by high-temperature flames depends largely upon the gases used and the pressure of the oxygen; the thicker the material, the higher the pressure required. When using the oxy-acetylene flame, it might be practicable to cut iron or steel up to 7 or 8 inches in thickness, whereas, with the oxy-hydrogen flame, the thickness could probably be increased to 20 or 24 inches. The oxy-hydrogen flame will cut thicker material principally because it is longer than the oxy-acetylene flame and can penetrate to the full depth of the cut, thus keeping all the oxide in a molten condition so that it can easily be acted upon by the oxygen cutting jet. A mechanically-guided torch will cut thick material more satisfactorily than a hand-guided torch, because the flame is directed straight into the cut and does not wabble, as it tends to do when the torch is held by hand. With any flame, the cut is less accurate and the kerf wider, as the thickness of the metal increases. When cutting light material, the kerf might not be over $\frac{1}{16}$ inch wide, whereas, for heavy stock, it might be $\frac{1}{4}$ or $\frac{3}{8}$ inch wide.

**Metals that can be Cut.** — Only wrought iron and steel can be cut by the oxy-acetylene flame. An appreciation of the real action which takes place during the cutting of iron or steel will make clear why cast iron and other metals cannot be cut. If a very thin strip of steel, such as a watch spring, is heated red-

hot and plunged into a jar of pure oxygen, the steel will immediately take fire and burn, and, if there is a sufficient amount of oxygen, the burning will continue until the steel is consumed. Again, if a piece of steel is heated red-hot and kept at this temperature, a simple jet of oxygen will cut through it, the requirements for cutting being that the metal be brought to a sufficiently high temperature to combine with the oxygen rapidly.

The other essential feature of the process is the removal of the oxide which results from the combining of the oxygen with the metal. In the case of ordinary low-carbon steel, the melting point of the metal is higher than the melting point of the oxide, and, as the action of the cutting is largely self-sustaining, that is, the heat from the melted slag materially helps to raise the temperature of the steel in contact with it to the necessary point for the continuation of the process, it appears that the slag will flow away without mixing with the metal.

**High-carbon Steel and Cast Iron.** — With high-carbon steels, the melting point of which is very nearly that of the oxide, there is a considerable tendency for the metal to melt under the heat of the slag and for the two to mix, preventing the oxygen from reaching the clean metal, as it does when the slag flows away smoothly. However, high-carbon steel can be cut, but, if an attempt is made to cut a piece of chilled iron, it will be found that, while the action starts, it will not continue; that is, the metal will not fly out of the cut in sparks, but will drop in little globules of melted metal. There is no graphite in chilled cast iron, all of the carbon being in the combined state, while, in ordinary cast iron, part of the carbon is in the form of graphite, which interferes with the action to an even greater extent than is the case with chilled iron, on account of the lack of continuity of the cast-iron grains between which the graphite is located; hence, cast iron cannot be cut by the oxy-acetylene torch.

**Malleable Iron.** — If malleable iron be tested with a cutting torch, it will be found that a white-heart casting, which is really a low-grade steel, will readily cut, because the percentage of carbon is lower than in the case of the chilled iron of which it

was made; while if a rather thick black-heart casting be tested, with an outer skin in which the percentage of carbon is low enough to entitle it to be called steel, and a center containing the same percentage of carbon as the chilled iron of which it was made (although its form has been changed to that of temper instead of combined carbon), it will be found impossible to cut. However, thin sections of black-heart malleable iron may be cut with satisfactory results. It should be understood, however, that the edges of the cut are not smooth, and that the action in the center of the piece is more that of melting than of cutting. For the results desired, however, these imperfections may be immaterial. Sections that can be cut with good results are not over $\frac{3}{8}$ inch thick, and generally not over $\frac{1}{4}$ inch.

**Different Gases Used.** — The use of the cutting process has been extended to exceedingly thick sections, particularly in the case of armor plate, as already referred to. As the oxy-acetylene flame is much shorter than the oxy-hydrogen flame, and as it is necessary to keep the slag in a melted condition, the longer flame is preferable, so that, for all heavy cutting, hydrogen is used rather than acetylene. With a more general introduction of electrolytic plants for the production of oxygen, the use of the oxy-hydrogen flame for cutting may be expected to develop at a rapid rate, as hydrogen, in this case, may be considered as a by-product. It also has the advantages of being free from danger when compressed to any pressure, and of being readily handled in tanks of the same light weight as oxygen tanks. Coal gas or ordinary illuminating gas, being largely composed of hydrogen, can also be used with very satisfactory results for cutting, and, in one case at least, it is used exclusively, being much cheaper than either acetylene or hydrogen. For the best results, however, each of these gases requires a torch with the openings properly proportioned and different from those for the other gases.

**Temperature of the Oxygen.** — One very important factor in the cost of cutting is the temperature of the oxygen in the cutting jet. Anyone who has handled oxygen tanks in cold weather knows that when the valve is open, and oxygen is allowed to escape at a fairly rapid rate, the valve body and other parts in

the vicinity become coated with snow or ice formed by the condensation of the moisture in the surrounding air. This is caused by the heat absorbed from these parts by the expansion of the gas. It is evident that under such conditions the issuing gas is very cold, and, when it is used in cutting, the tendency is to cool the slag and metal and delay the operation of the process. It would appear to be very easy to place a small steam coil around the head of the torch through which the oxygen used for cutting would pass, thus preheating it. In fact, such torches have been constructed, although, as far as the author knows, they are not in use in the United States; an increase in cutting speed of from 15 to 25 per cent is claimed for them. In the case of large cutting, the oxygen could be preheated in a special heater in the same way as is often done with compressed air.

**Effect of Heat on Steel.** — What effect has the heat from cutting on the steel in the vicinity of the cut? This point arises particularly in the case of high-carbon steel used for dies, a large number of these now being cut on automatic machines, particularly where the shape of the die is irregular. It can be stated with perfect confidence that no change occurs as far back as to injure the steel for this purpose, for while there is a slight decarburization of the steel, the depth to which it penetrates is less than the amount removed in finishing the die. An examination of annealed pieces under the microscope shows this to be the case, the structure being uniform after the annealing treatment, except for a distance of less than 0.020 inch from the cut surface. The change in the structure should preferably be remedied by annealing from above the recalescence point after the cutting is done, because the change in structure is always accompanied by some strain which would possibly cause trouble later by distorting the die when hardening. Of course, no good diemaker would think of hardening a piece of steel without removing the surface for at least $\frac{1}{32}$ inch to take off the decarburized portion. The same condition — and no worse — exists where oxy-acetylene cutting has been employed.

**Application of Oxy-acetylene Cutting Torch.** — An interesting application of the oxy-acetylene cutting torch is shown in Fig. 1.

This illustration is a reproduction of a photograph taken in the basement of the Warren Telephone Exchange at Syracuse, N. Y. The underground lead cables carrying the wires from the city telephones into the exchange enter from the street first into a manhole, which extends underneath the sidewalk to the wall of

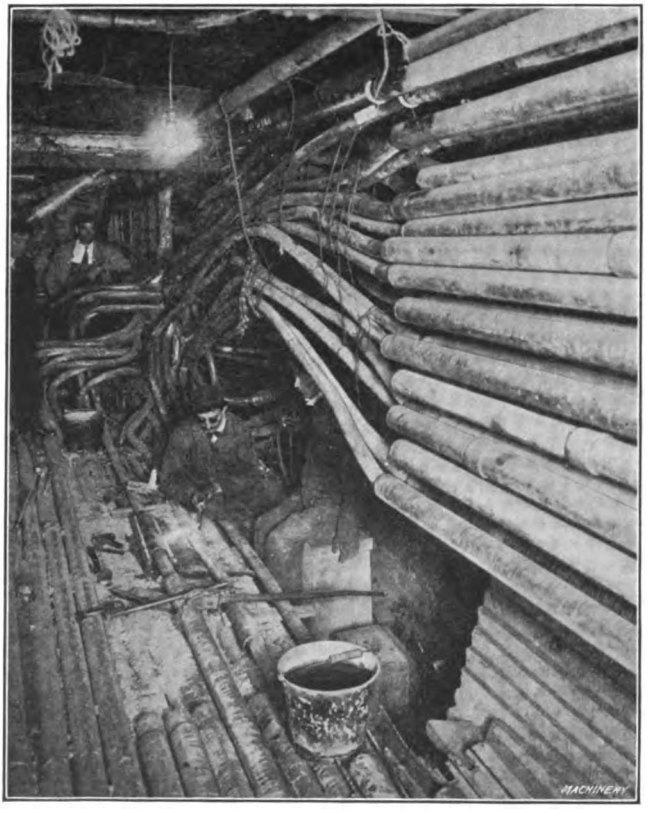



**Fig. 1. Oxy-acetylene Torch being used for Cutting away Iron Armor of Lead-covered Telephone Cables**

the building, and from there into the exchange room, the cables being encased in 3-inch iron pipes. An increase in the capacity of the exchange made an enlargement of the manhold necessary. At this time it became also necessary to remove the iron casings from the lead cables, so that the latter could be bent and

rearranged to make room for new ones. This difficult work was accomplished by the oxy-acetylene cutting torch, without damaging the lead cables underneath. This at first would appear to be an almost impossible proposition, as the melting point of lead is about 620 degrees F., while that of the pipe would be about 2500 degrees F., the oxy-acetylene flame itself having

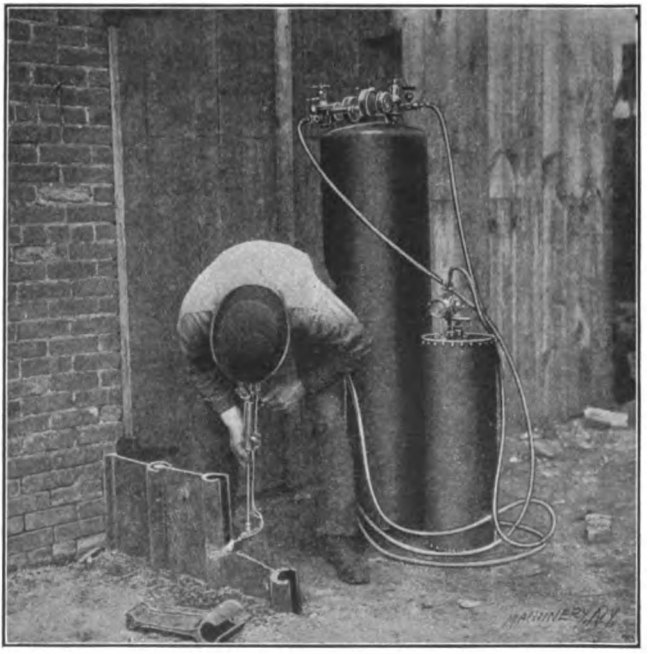


**Fig. 2. Cutting Off Steel Sheet Piling with Oxygen Cutting Torch, showing Portable Apparatus**

a temperature of over 6000 degrees F. The method used was as follows:

A copper shield about six feet long was slipped in between the cable and the casing; then the casing was cut around with the torch for a short distance and at a safe distance from the inner end of the shield, so as not to allow the flame to come too near to the lead cable; the casing was then rolled over a small amount, the shield readjusted, and another cut taken. This was continued until the casing was cut all the way around; it was then slid

back on the cable and split in two lengthwise, allowing the pieces to be removed. The reason for making the shields of copper is that the oxygen cutting jet, as already mentioned, will only cut wrought iron and steel, and does not have any cutting effect on copper.

**Cutting Metal under Water.** — A German engineer has designed a burner which makes it possible to use the oxy-hydrogen flame for cutting metals under water. The burner consists of a bell-shaped head which is screwed onto an ordinary burner and which allows the flame to continue to burn below the water in a supply of compressed air. This process has been so improved of late that the cutting of metals under water is claimed to be effected almost as quickly as above the surface. At tests made with the new apparatus at the harbor at Kiel, before prominent engineers and representatives of the German government, a diver went down into the sea to a depth of about 16 feet, and, after boring a hole into an iron bar $2\frac{1}{2}$ inches square, cut off the bar in about thirty seconds. An iron sheet $\frac{7}{8}$ inch thick was drilled through and cut for a distance of one foot in ninety seconds.

**Example of Metal Cutting.** — Fig. 2 illustrates the use of the cutting torch for cutting off steel sheet piling. This work is done with rapidity, and is a very spectacular performance. In the case of cutting, the combustion of the steel materially raises the temperature and assists in the work. This was pointed out by Chevalier C. de Schwarz in a paper read before the May, 1906, meeting of the Iron and Steel Institute, and it gives one a startling idea of the power of the oxygen cutting flame when the concentration of the heat units produced is known. Burning one pound of acetylene with oxygen produces from 18,250 to 21,500 B.T.U. The mean value may be taken as about 19,750 B.T.U. per pound, and the number of cubic feet at atmospheric pressure at about $14\frac{1}{2}$. Now, the burning of one pound of steel with oxygen produces approximately 2970 B.T.U., but, at atmospheric pressure, one pound of acetylene gas fills 6750 times the space of one pound of steel; hence, the intensity of the heat with perfect combustion of the steel in oxygen will be,

theoretically, $\frac{6750 \times 2970}{19{,}750} = 1015$ times the intensity of heat of the oxy-acetylene flame. As a matter of fact, this enormous temperature is not even remotely approached, because the metal dissolves at a far lower temperature and passes off in sparks, which are speedily cooled by the atmosphere.

**Cost of Cutting Metals with the Oxy-acetylene and Oxy-hydrogen Flame.** — The following figures will give an idea of

**Approximate Cost of Machine Cutting**

Oxygen at 3 cents per cubic foot, acetylene at 1 cent per cubic foot

| No. of Cutting Tip | Thickness of Steel, Inches | Pressure in Pounds | | Cubic Feet of Gas per Foot of Cut | | Inches Cut per Minute | Cost of Gas per Foot of Cut |
|---|---|---|---|---|---|---|---|
| | | Oxygen for Cutting | Oxygen for Heating | Oxygen | Acetylene | | |
| 2 | ¼ | 10 | 4 | 0.40 | 0.086 | 24 | $0.013 |
| 2 | ½ | 20 | 4 | 0.91 | 0.15 | 15 | 0.029 |
| 2 | ¾ | 30 | 4 | 1.16 | 0.15 | 15 | 0.036 |
| 2 | 1 | 30 | 4 | 1.45 | 0.172 | 12 | 0.045 |
| 2 | 1½ | 40 | 4 | 2.64 | 0.192 | 8 | 0.081 |
| 3 | 1 | 20 | 5 | 1.25 | 0.27 | 18 | 0.040 |
| 3 | 1½ | 30 | 5 | 2.40 | 0.38 | 12 | 0.076 |
| 3 | 2 | 40 | 5 | 2.96 | 0.38 | 12 | 0.093 |
| 3 | 3 | 50 | 5 | 5.37 | 0.57 | 8 | 0.167 |
| 4 | 3 | 40 | 5 | 7.23 | 0.75 | 8 | 0.224 |
| 4 | 4 | 50 | 5 | 9.70 | 0.80 | 7 | 0.299 |
| 4 | 5 | 60 | 5 | 15.00 | 1.00 | 5 | 0.460 |
| 4 | 6 | 70 | 6 | 21.09 | 1.50 | 4 | 0.648 |
| 4 | 7 | 80 | 6 | 25.00 | 1.50 | 4 | 0.765 |
| 4 | 8 | 90 | 6 | 28.50 | 1.50 | 4 | 0.870 |
| 4 | 9 | 100 | 6 | 43.20 | 2.00 | 3 | 1.311 |

the cost of cutting metals by the processes described. Assuming oxygen at 3 cents per cubic foot and acetylene at 1 cent per cubic foot, 2 feet of ¼-inch thick steel can be cut per minute at a cost of 1.3 cent per foot, and 1 foot of 1½-inch thick steel can be cut per minute at a cost of 7.6 cents per foot. This cost is for gas alone; the cost of labor must, of course, be added. The figures given are for machine-guided torches. When cutting with a hand-guided torch, the gas consumption will be approximately one-third more and the number of feet cut per hour, one-third less, than when the torch is mechanically guided by a special

## Gas Consumption when Cutting with Oxy-hydrogen Flame

(American Oxhydric Co.)

**Cutting with Machine Torch**

| Thickness, Inches | Time | | Gas Consumption in Cubic Feet | | | | Cost of Gases, Oxygen at 2½ cents, Hydrogen at 1¾ cent | | Width of Cut, Inch |
|---|---|---|---|---|---|---|---|---|---|
| | Seconds per Inch | Minutes per Foot | Per Lineal Inch, Cut | | Per Lineal Foot, Cut | | Per Lineal Inch | Per Lineal Foot | |
| | | | Oxy. | Hyd. | Oxy. | Hyd. | | | |
| ¼ | 5.0 | 1 | 0.125 | 0.125 | 1.5 | 1.5 | $0.0053 | $0.0638 | 1/16 |
| ½ | 5.0 | 1 | 0.208 | 0.208 | 2.5 | 2.5 | 0.0088 | 0.1059 | ⅛ |
| ¾ | 5.0 | 1 | 0.25 | 0.25 | 3.0 | 3.0 | 0.0105 | 0.1266 | ⅛ |
| 1 | 7.5 | 1 5/16 | 0.291 | 0.275 | 3.5 | 3.3 | 0.0121 | 0.1451 | ⅛ |
| 1½ | 7.5 | 1 5/16 | 0.366 | 0.316 | 4.4 | 3.8 | 0.0147 | 0.1762 | ⅛ |
| 2 | 7.5 | 1 5/16 | 0.5 | 0.333 | 6.0 | 4.0 | 0.0183 | 0.2200 | ⅛ |
| 2½ | 10.0 | 2 | 0.65 | 0.366 | 7.8 | 4.5 | 0.0226 | 0.2719 | ¼ |
| 3 | 10.0 | 2 | 0.8 | 0.416 | 9.6 | 5.0 | 0.0273 | 0.3274 | ¼ |
| 3½ | 10.0 | 2 | 1.0 | 0.5 | 12.0 | 6.0 | 0.0337 | 0.4050 | ¼ |
| 4 | 15.0 | 3 | 1.33 | 0.633 | 16.0 | 7.6 | 0.0443 | 0.5320 | ¼ |
| 4½ | 15.0 | 3 | 1.63 | 0.775 | 19.5 | 9.3 | 0.0593 | 0.7117 | ¼ |
| 5 | 15.0 | 3 | 1.88 | 0.833 | 22.6 | 9.8 | 0.0616 | 0.7388 | ¼ |
| 5½ | 15.0 | 3 | 2.08 | 0.875 | 25.0 | 10.5 | 0.0673 | 0.8077 | ¼ |
| 6 | 15.0 | 3 | 2.29 | 0.926 | 27.5 | 11.2 | 0.0734 | 0.8814 | ¼ |
| 6½ | 15.0 | 3 | 2.66 | 1.0 | 32.0 | 12.0 | 0.084 | 1.0 | ¼ |
| 7 | 24.0 | 4 8/10 | 3.13 | 1.25 | 37.6 | 15.0 | 0.10 | 1.20 | ¼ |
| 8 | 25.0 | 5 | 3.33 | 1.41 | 40.0 | 17.0 | 0.1079 | 1.295 | ¼ |
| 9 | 26.0 | 5 3/10 | 4.16 | 1.66 | 50.0 | 20.0 | 0.1330 | 1.5966 | ¼ |
| 12 | 28.0 | 5 8/10 | 7.0 | 2.5 | 84.0 | 30.0 | 0.175 | 2.10 | ⅜ |
| 15 | 30.0 | 6 | 8.16 | 4.5 | 98.0 | 54.0 | 0.2827 | 3.407 | ⅜ |
| 23 | 35.0 | 7 | 19.5 | 6.0 | 234.0 | 72.0 | 0.5925 | 7.11 | ⅜ |

**Cutting with Hand Torch**

| Thickness, Inches | Time | | Gas Consumption in Cubic Feet | | | | Cost of Gases, Oxygen at 2½ cents, Hydrogen at 1¾ cent | |
|---|---|---|---|---|---|---|---|---|
| | Seconds per Inch | Minutes per Foot | Per Lineal Inch, Cut | | Per Lineal Foot, Cut | | Per Lineal Inch | Per Lineal Foot |
| | | | Oxy. | Hyd. | Oxy. | Hyd. | | |
| 1/16 | 6.0 | 1 2/10 | 0.23 | 0.24 | 2.76 | 2.88 | $0.0099 | $0.1194 |
| ⅛ | 6.0 | 1 2/10 | 0.24 | 0.24 | 2.88 | 2.88 | 0.0102 | 0.1224 |
| 1 | 6.5 | 1 3/10 | 0.35 | 0.32 | 4.2 | 3.84 | 0.0143 | 0.1722 |
| 1½ | 7.5 | 1 5/10 | 0.40 | 0.34 | 4.8 | 4.08 | 0.0159 | 0.1914 |
| 2 | 8.0 | 1 6/10 | 0.56 | 0.44 | 6.72 | 5.28 | 0.0217 | 0.2604 |
| 2½ | 8.5 | 1 7/10 | 0.76 | 0.52 | 9.12 | 6.24 | 0.0281 | 0.3372 |
| 3 | 9.5 | 1 9/10 | 1.04 | 0.72 | 12.48 | 8.64 | 0.0386 | 0.4632 |
| 3½ | 12.0 | 2 4/10 | 1.2 | 0.9 | 14.4 | 10.8 | 0.0457 | 0.549 |
| 4 | 15.0 | 3 | 1.55 | 1.05 | 18.6 | 12.6 | 0.0571 | 0.6854 |
| 4½ | 17.0 | 3 4/10 | 1.9 | 1.15 | 22.8 | 13.8 | 0.0676 | 0.8112 |
| 5 | 20.0 | 4 | 2.4 | 1.3 | 28.8 | 15.6 | 0.0827 | 0.993 |
| 5½ | 22.0 | 4 4/10 | 2.6 | 1.5 | 31.2 | 18.0 | 0.0912 | 1.095 |
| 6 | 23.5 | 4 7/10 | 2.8 | 1.65 | 33.6 | 19.1 | 0.0989 | 1.186 |
| 6½ | 25.0 | 5 | 3.1 | 1.8 | 37.2 | 21.6 | 0.109 | 1.30 |
| 7 | 28.0 | 5 6/10 | 3.73 | 1.95 | 44.7 | 23.4 | 0.1342 | 1.61 |
| 8 | 30.0 | 6 | 4.0 | 2.1 | 48.0 | 32.4 | 0.137 | 1.644 |

cutting machine. The variation, of course, depends, to some extent, upon the skill of the operator.

When cutting with the oxy-hydrogen flame and assuming the cost of oxygen at 3 cents per cubic foot, and the cost of hydrogen at $1\frac{3}{4}$ cent per cubic foot, the cost of the gas per foot for cutting $\frac{1}{4}$-inch thick steel is about 7 cents and the cost of cutting $1\frac{1}{2}$-inch thick steel, about 18 cents per lineal foot. Cutting with a hand torch increases the cost slightly. While the oxy-hydrogen process is thus more expensive than the oxy-acetylene process for thin stock, it has the advantage that it can be used on much heavier material than the oxy-acetylene flame, as explained in a previous paragraph.

**Difficulty of Making Accurate Cost Estimates.** — In view of such difficulties as blow-holes in steel castings, scale on sheets, etc., it is generally unsafe for a welding shop to make a flat or contract price on any cutting job, even after an inspection of the work to be done. A better plan is to cover the labor charge and overhead expenses, profit, etc., by an hourly rate, and make a reasonable charge for the gases used. The gas consumption cannot be determined except by separating the gases used by the heating and auxiliary jets, respectively. A fairly accurate figure for the gases used by the heating jets can be obtained from the manufacturers of the torch, but the oxygen used in the auxiliary jet will vary so much, due to the opening and closing of the valve and the change of pressure necessary for the requirements of the case, that it is impossible to do any more than guess at the amount consumed, by reading the gage on the oxygen tank. Of course, in the case of a long job, the total amount of oxygen can be obtained quite accurately from the number of tanks used, but this cannot be used as a basis for other jobs without considerable risk.

**Increasing the Efficiency of the Cutting Torch.** — Experiments recently conducted in cutting with oxy-hydrogen and oxy-acetylene cutting torches show that a marked increase in the rate of production is effected by increasing the temperature of the oxygen. The most favorable results secured in this connection show that the increase of speed obtained by preheating

the oxygen is 18 per cent, while the saving in the amount of oxygen used is 55 per cent. As an increase in temperature means a corresponding increase in the pressure of the oxygen, it seemed possible that merely increasing the pressure would have the same effect. Experiments along this line proved that this reasoning was correct. Where the pressure was steadily increased, it was found that the rate of cutting increased in direct proportion. It was found, however, that the higher pressures had a tendency to round the upper edge of the cut. A pressure of 35.5 pounds per square inch seems to be about the maximum amount with which perfect work could be produced. With very low pressures, the rate of cutting was not only very slow, but the cut itself was defective. Experiments were also tried in changing the ratio of hydrogen to oxygen, and it was found that, where this ratio was 15 to 4 instead of the customary 4 to 1, the rate of cutting was exceptionally high in cases where the pressure of the oxygen was about the maximum of 35.5 pounds per square inch.

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